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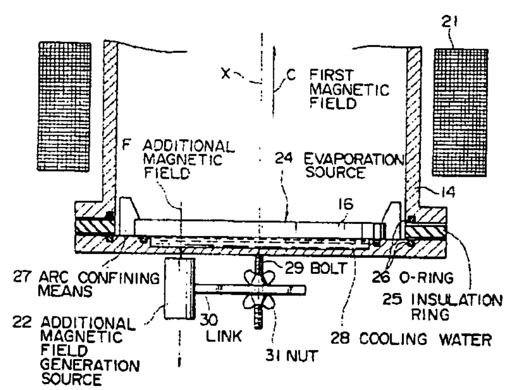
(54) Method of controlling an arc spot in vacuum arc vapor deposition and an evaporation source.

(57) A vacuum arc vapor deposition device comprising a vacuum processing chamber, a vacuum arc evaporation source disposed in the vacuum processing chamber, excitation coils disposed to the outside of the vacuum processing chamber so as to surround the evaporation surface of a cathode in the vacuum arc evaporation source, and an additional magnetic field generation source disposed near the rear side of the evaporation surface.

By the combination of a magnetic field formed with the excitation coils and an opposite magnetic field formed with the additional magnetic field generation source, efficient use of the evaporation source target, use of a plurality of materials, effective converging of the plasma beam and efficient deposition to the substrate can be attained.

F I G. 4



EP 0 495 447 A1

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an improved to a vacuum arc vapor deposition technique for forming a deposition film in vacuum on a substrate.

Description of the Prior Art

The vacuum arc vapor deposition is fundamentally executed according to such a method as to evaporate an evaporation material from an evaporation source (cathode) by arc discharge in a vacuum chamber and to then deposit it on a substrate applied with a negative bias voltage, wherein the vapor of the cathodic material with a high energy is emitted as a plasma beam from a cathode as an evaporation source by a high arc current, and accelerated by a voltage applied between the cathode and the substrate to form a deposition film on the substrate (refer to Japanese Patent Publication Sho 58-3033).

As an improved form of such a vacuum arc vapor deposition device, there has been known a device for introducing the plasma beam generated from the evaporation source by utilizing magnetic fields to improve the directionality thereof and effectively introducing the same to a substrate. Fig. 10 shows a typical example of such a device.

When a deposition film is formed on the surface of a substrate a as an object to be processed in this device, a target d of a conductive material as a film formation component is attached to a cathode e in a vacuum processing chamber c evacuated by a vacuum pumping system b, the vacuum processing chamber serving also as an anode in this embodiment and a cathode are connected to an arc power source f, vacuum arc discharge is caused between both of the electrodes by an arc discharge ignition means (not illustrated), the target material is evaporated and ionized from an arc spot formed on an evaporation surface g of the cathode, a plasma beam h is formed with the ions and electrons emitted from the arc spot and it is deposited on the surface of the substrate a. In this case, if necessary a negative voltage is applied to the substrate a, or a reaction gas introduced from a reaction gas system i and the vapor of the target material are brought into reaction to form a deposition film of a compound.

Further, in this device, magnetic fluxes j passing through the evaporation surface of the cathode are extended near the substrate and the plasma beam is introduced at a high directionality to the substrate by utilizing the nature of the plasmas that they tend to be introduced along the direction of the magnetic fluxes, to improve the film formation rate. For forming such magnetic fields, excitation coils k substantially in coaxial with the evaporation surface are disposed at a position near the evaporation surface of the cathode so as to surround the evaporation surface. In Fig. 10, the excitation coils k are disposed somewhat ahead of the evaporation surface, but they may be disposed at different positions depending on the purpose, with such a shape that the magnetic fluxes formed by the coils passes through the evaporation surface.

Application of magnetic fields to the vacuum arc vapor deposition technique are also made in various other modes.

Japanese Patent Laid-Open Hei 1-312067 discloses a vacuum arc vapor deposition device utilizing cusped magnetic fields in the prior art.

As shown in Figs. 11 and 12, the vacuum arc vapor deposition device comprises magnetic poles constituted with a pair of electromagnetic coils k1, k2 or permanent magnets opposed to each other at an identical polarity disposed along an identical axial line X in a vacuum processing chamber Cl having a cross shaped vertical cross section to form cusped magnetic fields CF in a space between both of the poles in the vacuum processing chamber. A vacuum arc evaporation source with a film formation material is disposed in the vicinity of at least one of positions where the cupsed magnetic fields are converged into a spot and the magnetic field intensity becomes maximum with an evaporation surface gl being directed to the center of the magnetic field. A substrate al is disposed in the vicinity of a position at the periphery of a central plane S along which the magnetic fields are diverged, and is further situated at such a non-perspective position as optically hidden from an evaporation source of the vacuum arc evaporation source by optical shield of intervening matters present therebetween.

In this device, a plasma stream having electric charges generated from the evaporation source by the vacuum arc flows out under the effect of the magnetic fields from the position on the central plane S along which the cusped magnetic fields are diverged and deposited to form a film on the substrate, while neutral macroparticles proceed straight forward free from the effect of the magnetic fields and are prevented from intruding into the deposition film on the substrate situated at a shielded position.

In the vacuum arc vapor deposition device of the prior art described above, since an arc spot formed by the vacuum arc that causes evaporation from the evaporation source has a nature of displacing at random on the evaporation surface, the arc spot can not be controlled to be present only in a specified local region on the evaporation surface. Accordingly, evaporation occurs from the entire area of the evaporation surface to make the plasma beam diverged widely as shown in Fig. 11.

In a case where the substrate to be processed is relatively small as compared with the extent of the plasma beam, a considerable portion of the plasmas

evaporated from the evaporation surface can not reach the substrate but are merely deposited wastefully on each of the portions in the vacuum processing chamber. Further, it is also difficult to focus the plasma beam at a high plasma density to a restricted portion.

In addition, in the vacuum arc vapor deposition device using cusped magnetic fields shown in Figs. 11 and 12, since the evaporation surface gl of the evaporation source and the magnetic field generation coils k1, k2 are on the central axial line X, the substrates al have to be disposed so as to be at the entire circumferential positions around the central axial line as shown in Fig. 12.

However, in a case where the number of substrates to be processed is small, since it is impossible to surround the entire circumference of a large diameter at the periphery of the central axial line with no wasteful gaps, most of evaporation products such as ions can not be vapor deposited on the substrate but wastefully consumed by being deposited to the inner walls of the vacuum chamber cl, which brings about a problem of lowering the vapor deposition efficiency.

SUMMARY OF THE INVENTION

The present invention has been accomplished with an aim of solving the foregoing problems in the prior art and enabling control of an arc spot to be focused, control of the arc spot for the position of the focused region, as well as high density converging of plasma beam.

The method of controlling the arc spot is characterized in that, in a vacuum arc vapor deposition device comprising excitation coils disposed near the evaporation surface of a cathode as a vacuum arc evaporation source substantially in coaxial with the evaporation surface, so as to surround it, and a first magnetic fields passing through the evaporation surface are formed by excitation, an additional magnetic field generation source comprising small excitation coils or permanent magnets that generate magnetic fields in the direction opposite to that of the first magnetic fields is disposed near the rear side of the evaporation surface, to operate them in combination.

By the method of controlling the arc spot and the evaporation source for enabling to practice the method according to the present invention, the arc spot causing the evaporation from the evaporation surface can be induced to a restricted region of the evaporation surface ahead of the additional magnetic field generation source.

The function will be now described.

Assuming, at first as shown in Fig. 1, that an arc spot 3 of a vacuum arc is formed on an evaporation surface 1 of a cathode and there are present magnetic fluxes 4 passing through the evaporation surface at an angle, it has been known that the arc spot moves under the interaction between the horizontal component 5 of the magnetic fields and the current 2 flowing through the arc spot, while undergoing an electromagnetic force in the direction perpendicular to both of them, that is, in the direction perpendicular to the sheet of drawing in Fig. 1, as well as tends to move under the effect of the vertical component 6 of the magnetic fields in a case where magnetic fluxes pass through the evaporation surface at an angle of inclination in the direction where the magnetic fluxes are inclined at an acute angle relative to the evaporation surface, that is, in the rightward direction in Fig. 1 (refer to U.S. Patent No. 2,972,695).

Referring then to the present invention, as shown in Fig. 2, excitation coils 8 substantially coaxial with an evaporation surface 7 of a cathode as a vacuum arc evaporation source are disposed near the evaporation surface 7 so as to surround the evaporation surface and, they are excited to generate a first magnetic field comprising magnetic fluxes that pass through the evaporation surface. Further, an additional magnetic field generation source 10 for generating magnetic fluxes in the direction opposite to the first magnetic field is disposed in the vicinity of the rear side of the evaporation surface to generate an additional magnetic field 11 shown by the dotted line. When they are combined to each other, magnetic fluxes 9 extended outward rear the additional magnetic generation source are formed, and a distribution shape of magnetic fluxes directing to the central axis are obtained near the evaporation surface by the magnetic fluxes. Considering the above-mentioned shape together with the fact that the arc spot undergoes the force in the direction of making an acute angle formed when the magnetic fluxes pass through the evaporation surface as explained with reference to Fig. 1, the arc spot undergoes a force 12 shown by fat arrows toward the region ahead of the additional magnetic field generation source on the evaporation surface.

As has been described above, the arc spot of the vacuum arc vapor deposition in the present invention does not move around at random over the entire region of the evaporation surface as in the prior art but it is trapped so as to be confined within a restricted region in the vicinity ahead of the additional magnetic field generation source on the rear side of the evaporation surface, so that evaporation of the film formation material occurs only at the focused region.

The effect of the present invention is confirmed not only theoretically but also experimentally, and it has been observed that the arc spot is trapped and moves circumferentially at a high speed in a small region on the evaporation surface ahead of the additional magnetic field generation source of the permanent magnets. Further, it has also been confirmed that the extent of the region in which the arc spot is trapped varies by changing the distance between the additional magnetic field generation source and the

evaporation source and that the extent of the region in which the arc spot is trapped varies by changing the disposing position and the excitation intensity of the additional magnetic field generation source, as well as it has been found that the controllability is also excellent.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an explanatory view illustrating the effect of magnetic fluxes exerted on an arc spot on an evaporation surface;

Fig. 2 is a view illustrating the shape of magnetic fluxes generated on the evaporation surface in the present invention;

Fig. 3 is a vertical cross sectional view of a device as an typical embodiment according to the present invention;

Fig. 4 is an enlarged cross sectional view for a portion of a second embodiment illustrating the state of mounting an additional magnetic field generation source according to the present invention;

Fig. 5 is a top plan view for the mounting portion in the second embodiment;

Fig. 6 is an enlarged cross sectional view for a portion of a third embodiment illustrating the additional magnetic field generation source according to the present invention;

Fig. 7 is a plaan view of a mosaic composite target used in the third embodiment of the present invention;

Fig. 8 is a vertical cross sectional view of a fourth embodiment using cusped magnetic fields according to the present invention;

Fig. 9 is a transversal cross sectional view at the central plane in the device shown in Fig. 8;

Fig. 10 is a vertical cross sectional view of a vacuum arc vapor deposition device as one embodiment of the prior art;

Fig. 11 is a vertical cross sectional view of a device using a cusped magnetic field as another embodiment of the prior art; and

Fig. 12 is a transversal cross sectional view at the central plane of the device shown in Fig. 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more specifically by way of the embodiments with reference to the drawings. Further, additional advantages obtained by the device in each of the embodiments will be shown together.

[Embodiment 1]

Fig. 3 shows a typical embodiment of a device used for practicing the present invention. The device is identical, as a whole, with the device of the prior art shown in Fig. 10, in which a substrate 15 as an object to be processed is contained in a vacuum processing chamber 14 evacuated by a vacuum pumping system 13, a target 16 composed of a film formation material is attached to a cathode 17 being opposed thereto, the vacuum processing chamber also serving as an anode and a cathode are connected to an arc power source 18, arc discharge is caused by an arc discharge ignition means between both of the poles, and the film formation material is evaporated by the arc spot from the evaporation surface 19 of the cathode, to form a plasma beam 20.

Excitation coils 21 are disposed surrounding the evaporation surface 19 and are excited to form magnetic fields in which the magnetic fluxes pass through the evaporation surface of the cathode. An additional magnetic field generation source 22 comprising permanent magnets is disposed near the rear side of the evaporation surface to generate magnetic fields in the direction opposite to that of the magnetic fields described previously for practicing the present invention.

The permanent magnets may be replaced with electromagnetic coils for generating similar magnetic fields.

The arc spot causing evaporation of the film formation material from the evaporation surface is trapped by an orbit drawing a circle in a small arc spot region 23 on the evaporation surface ahead of the additional magnetic field generation source 22 by the cooperation between both of the magnetic fields. The plasma beam 20 generated from the arc spot trapped in the small region also undergoes induction by the magnetic field substantially is perpendicular to the first evaporation surface to form a strongly directing converged beam shown in the figure, and introduced on the substrate to form a deposition film.

Accordingly, a deposition film can be formed efficiently even in a case where the substrate is small and, since the density of the plasmas obtained near the substrate is high, a deposition film at a high quality can be formed.

[Embodiment 2]

The present invention can provide various other additional advantages depending on the mode of disposing the additional magnetic field generation source.

Figs. 4 and 5 show enlarged cross sectional views for a portion in which an additional magnetic field generation source 22 comprising permanent magnets is disposed vertically. In the figures, components and members identical with those in Embodiment 1 shown in Fig. 3 carry the same reference numerals with no duplicate descriptions.

A target 16 of an evaporation source 24 for

vacuum arc vapor deposition is attached to a vacuum processing chamber 14 by means of an insulation ring 25 while being sealed by an O-ring 26. A target for a film formation material is attached on the surface being surrounded with an arc confining means 27, and cooled by cooling water 28 passing the rear side thereof. A bolt 29 is disposed at a position for the central axis X on the rear side of the evaporation source, and a link 30 having a long hole 30' secured to the additional magnetic field generation source 22 of the permanent magnets is clamped by nuts 31 and attached to the bolt 29.

The direction of the additional magnetic field F by the additional magnetic field generation source 22 is made opposite to the direction of the first magnetic field C generated from the excitation coils 21.

With such a structure, the additional magnetic field generation source 22 of the permanent magnets can be set on the rear side of the target 16 of the evaporation surface while being moved optionally both in the radial direction and the circumferential direction independently. The arc spot can be controlled to a desired position within the evaporation surface in accordance with the movement of the generation source 22. Further, the distance of the additional magnetic field generation source from the evaporation surface can also be varied with ease, by which the size of a region to which the arc spot is trapped in the evaporation surface and, accordingly, the converging degree, that is, the intensity of the plasma beam can be varied to adapt it to the size of the substrate. The excitation intensity or the shape of the additional magnetic field generation source can be changed by replacing the permanent magnets. The same effect can be attained also by using electromagnetic coils instead of the permanent magnets.

within evap surface

[Embodiment 3]

The additional magnetic field generation source is semi-fixed in Embodiment 2, but a preferred result can be obtained, in a case where the target of the cathode is circular, by rotationally driving the magnetic field generation source coaxially with the circular evaporation surface using a driving source.

Fig. 6 shows such an embodiment, in which identical components and members with those in the previous embodiment carry the same reference numerals with no duplicate descriptions. In this example, an additional magnetic field generation source 22 is rotationally moved around a central axis X by a driving motor 32.

In the prior art, since the arc spot basically moves at random on the evaporation surface, the central portion is mainly evaporated to be consumed sooner or the arc spot is localized to consume only a portion greatly. In Embodiment 3 of the present invention, since the arc spot is trapped in a region of an appropriate size and the region is moved circumferentially on the evaporation surface, the target can be consumed extremely uniformly to improve the efficiency of utilizing the material.

In the device shown in Fig. 6, a deposition film comprising alloying elements can be obtained stably by constituting a target into a composite target 16A in which two or more kinds of film formation materials 16a, 16b are combined in a mosaic form as shown in Fig. 7. In the prior art, since the arc spot often concentrates on the material, among two or more kind of materials, that can be present stably, the composition of the deposition film may possibly be deviated from the aimed one. However, in the present invention, since the region 23 in which the arc spot is present is controlled properly and the region is moved rotationally in this embodiment, both of the materials 16a, 16b can be evaporated uniformly to stabilize the composition of the deposition film.

As a further application of this example, deposition films of different compositions can be obtained stably by controlling the moving speed of the additional magnetic field generation source depending on the angular position.

[Embodiment 4]

The present invention is applicable also to a vacuum arc vapor deposition device using the cusped magnetic fields. Fig. 8 and 9 illustrate such an embodiment, in which identical components and members with those shown in Figs. 11 and 12 for the prior art carry the same reference numerals with no duplicate descriptions.

In this example, a bar-shaped permanent magnet is attached at a position just in the vicinity on the rear side of an evaporation source 33 while being deviated from a central axis X to constitute an additional magnetic field generation source 34. The direction of the additional magnetic field F generated is made opposite to the direction of the primary magnetic field caused by excitation coils 35. The additional magnetic field generation source 34 may be electromagnetic coils instead of the permanent magnet so long as the foregoing conditions can be satisfied.

A substrate 37 is disposed in the periphery of a position on the central plane S along which cusped magnetic fields are diverged in a vacuum processing chamber 36 at a position optically shielded from an evaporation source by the walls of the vacuum processing chamber 36. In this embodiment, three substrates 37 are disposed each being deviated in the same direction as the direction along which the additional magnetic fields generation source 34 is deviated from the central axis X.

In the device of this embodiment, an arc spot 38 appearing on the evaporation surface of the evaporation source 33 by vacuum arc discharge is trapped

by an orbit drawing a circle near the position on which the additional magnetic field generation source 34 is disposed as shown in Fig. 9. Since the plasma beam generated from the evaporation surface by the arc spot is induced along the magnetic fluxes of the magnetic field deviated from the symmetric cusped shape shown in Fig. 8, plasmas fly mainly leftward as shown by fat arrows A in Fig. 9 and contribute to the vapor deposition to the three substrates disposed in this direction. That is, vapor deposition products flying in the direction in which no substrates are present can be minimized to improve the efficiency for the vapor deposition. Further, by making the additional magnetic field generation 34 movable as in the embodiments shown in Figs. 4 and 8, it is possible to scan the plasmas and control the localized position for vapor deposition.

As has been described above according to the present invention, since the arc spot can be controlled to a predetermined region on the evaporation surface, a converged high density plasma beam can be obtained and a deposition film can be formed even on a small substrate with less loss and at high quality. In addition, being coupled with the improvement for the constitution of the device, there can be obtained various advantages capable of optionally controlling the position and the size of the plasma beam, making the consumption of the target uniform and stabilizing the composition of the alloyed deposition film.

A vacuum arc vapor deposition device comprising a vacuum processing chamber, a vacuum arc evaporation source disposed in the vacuum processing chamber, excitation coils disposed to the outside of the vacuum processing chamber so as to surround the evaporation surface of a cathode in the vacuum arc evaporation source, and an additional magnetic field generation source disposed near the rear side of the evaporation surface.

By the combination of a magnetic field forced with the excitation coils and an opposite magnetic field formed with the additional magnetic field generation source, efficient use of the evaporation source target, use of a plurality of materials, effective converging of the plasma beam and efficient deposition to the substrate can be attained.

Claims

1. A vacuum arc vapor deposition device comprising:

   a vacuum processing chamber,

   a vacuum arc evaporation source disposed in the vacuum processing chamber,

   excitation coils disposed to the outside of the vacuum processing chamber so as to surround the evaporation surface of a cathode in the vacuum arc evaporation source, and

   an additional magnetic field generation source disposed near the rear side of said evaporation surface.

2. A vacuum arc vapor deposition device as defined in claim 1, wherein the excitation coils form a magnetic field passing through the evaporation surface.

3. A vacuum arc vapor deposition device as defined in claim 2, wherein the additional magnetic field generation source form a magnetic field in the direction opposite to the magnetic field formed by the excitation coils.

4. A vacuum arc vapor deposition device as defined in claim 3, wherein the additional magnetic field generation source comprises permanent magnets.

5. A vacuum arc vapor deposition device as defined in claim 3, wherein the additional magnetic field generation source comprises electromagnetic coils.

6. A vacuum arc vapor deposition device as defined in claim 3, wherein the magnetic field formed by the excitation coils has a cusped shape.

7. A vacuum arc vapor deposition device as defined in claim 6, wherein the additional magnetic field generation source is disposed just in the vicinity on the rear side of the vacuum arc evaporation source being deviated from the central axis for the vacuum arc evaporation source.

8. A vacuum arc vapor deposition device as defined in claim 7, wherein a substrate to be vapor deposited with vapor of a film formation material from the vacuum arc evaporation source is attached at a position optically shielded from the vacuum arc evaporation source by the wall of the vacuum processing chamber.

9. A vacuum arc vapor deposition device as defined in claim 3, wherein the additional magnetic field generation source is held by an additional magnetic field generation source holding means disposed on the rear side of the evaporation source.

10. A vacuum arc vapor deposition device as defined in claim 9, wherein the additional magnetic field generation source holding means comprises a link having a long hole and attached to the additional magnetic field generation source, a bolt disposed to the rear side of the evaporation source and passing through said link having the long hole and a plurality of nuts for engagement

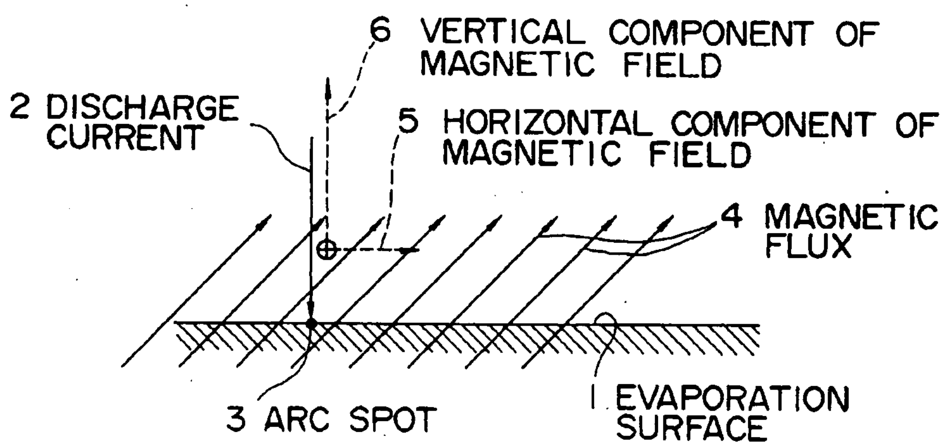
with said bolt.

11. A vacuum arc vapor deposition device as defined in claim 9, wherein the additional magnetic field generation source holding means is connected with a driving motor, so that the additional magnetic field generation source is rotationally moved around the central axis for the evaporation source.

12. A vacuum arc vapor deposition device as defined in claim 11, wherein the moving speed of the additional magnetic field generation source is controlled depending on the angular position.

13. A vacuum arc vapor deposition device as defined in claim 11, wherein the target disposed to the vacuum arc evaporation source is a composite target comprising a plurality of film formation materials combined in a mosaic form.

F I G. 1


6 VERTICAL COMPONENT OF MAGNETIC FIELD
2 DISCHARGE CURRENT
5 HORIZONTAL COMPONENT OF MAGNETIC FIELD
4 MAGNETIC FLUX
3 ARC SPOT
1 EVAPORATION SURFACE

F I G. 2

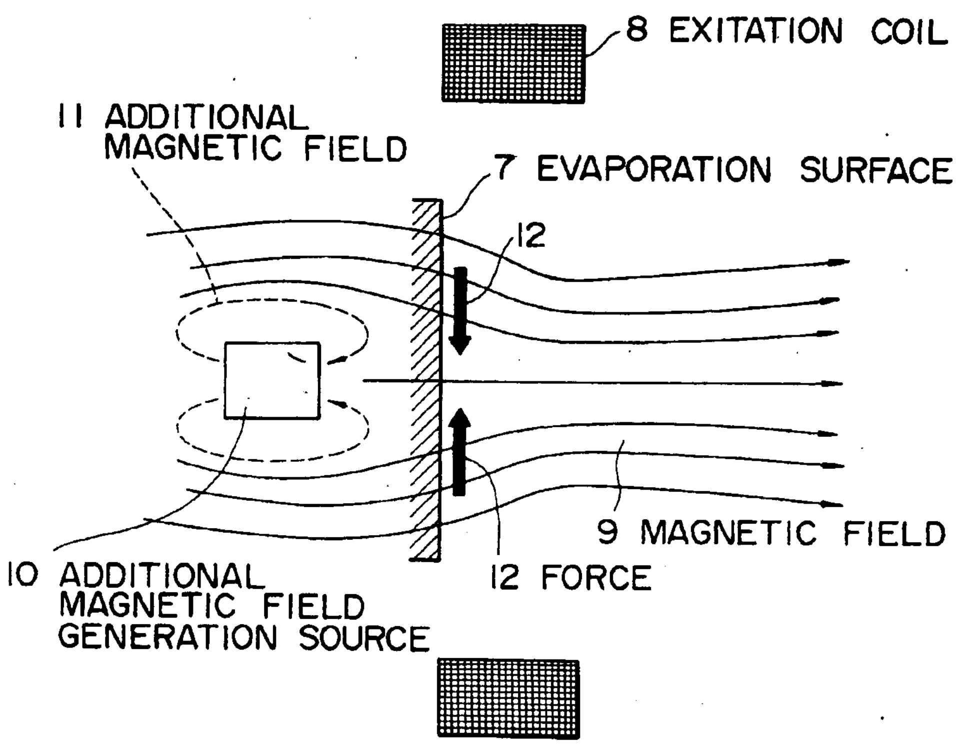

8 EXITATION COIL
11 ADDITIONAL MAGNETIC FIELD
7 EVAPORATION SURFACE
12
9 MAGNETIC FIELD
10 ADDITIONAL MAGNETIC FIELD GENERATION SOURCE
12 FORCE

FIG. 3

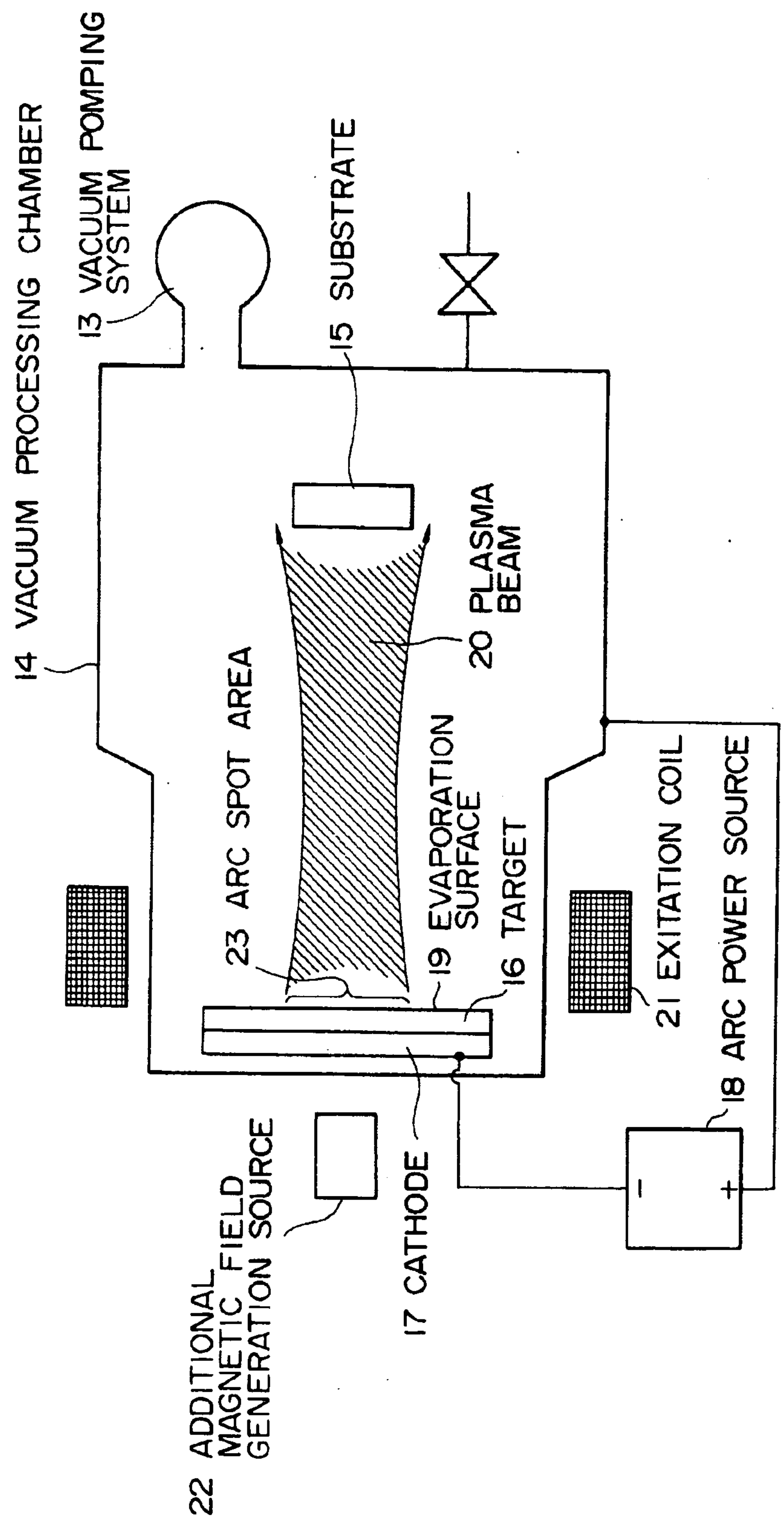

14 VACUUM PROCESSING CHAMBER
13 VACUUM POMPING SYSTEM
15 SUBSTRATE
20 PLASMA BEAM
23 ARC SPOT AREA
19 EVAPORATION SURFACE
16 TARGET
21 EXITATION COIL
18 ARC POWER SOURCE
-
+
17 CATHODE
22 ADDITIONAL MAGNETIC FIELD GENERATION SOURCE

FIG. 4

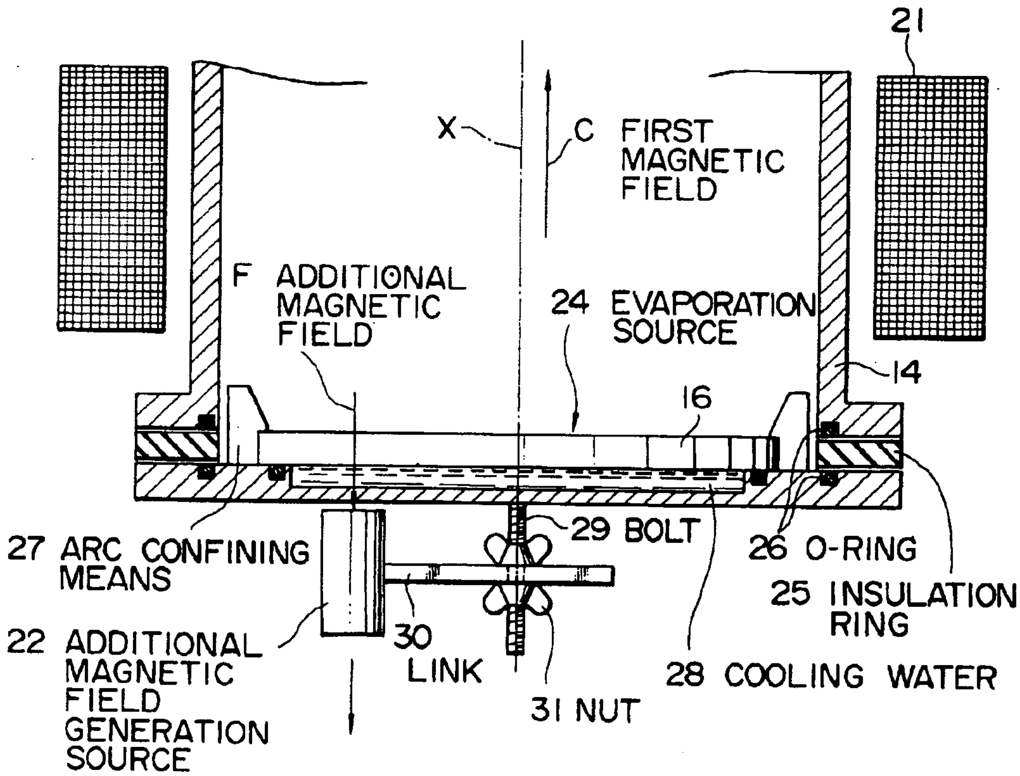

21
X
C FIRST MAGNETIC FIELD
F ADDITIONAL MAGNETIC FIELD
24 EVAPORATION SOURCE
14
16
29 BOLT
26 O-RING
27 ARC CONFINING MEANS
25 INSULATION RING
22 ADDITIONAL MAGNETIC FIELD GENERATION SOURCE
30 LINK
28 COOLING WATER
31 NUT

FIG. 5

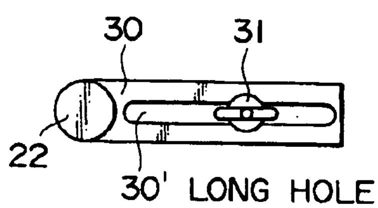

30
31
22
30' LONG HOLE

FIG. 6

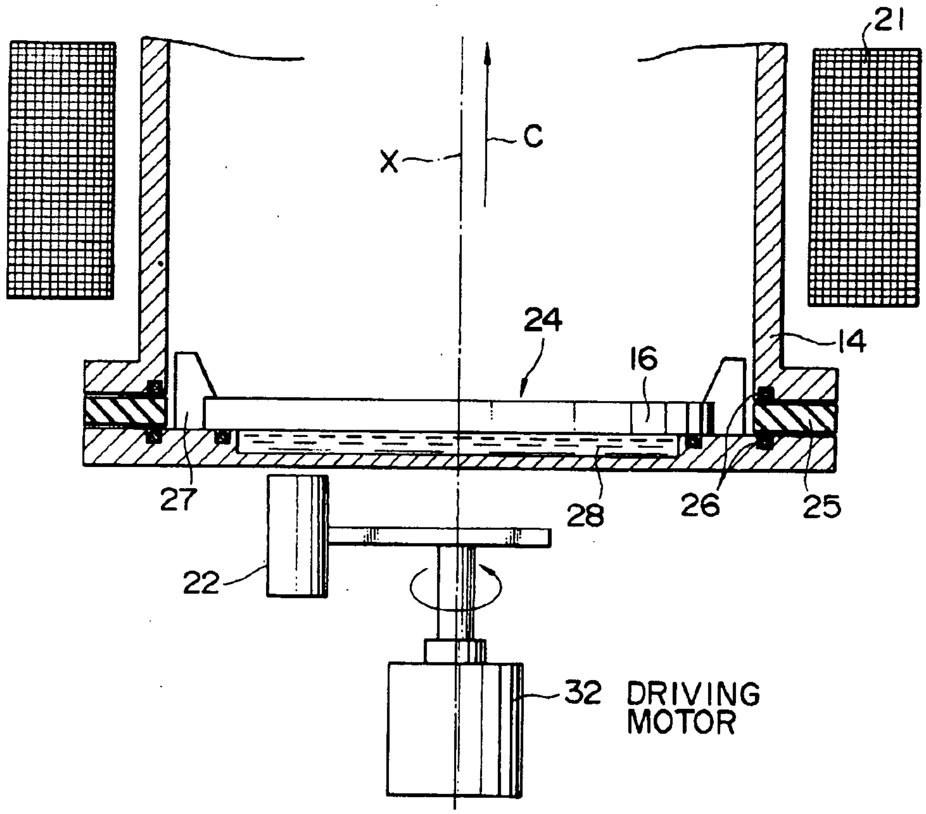
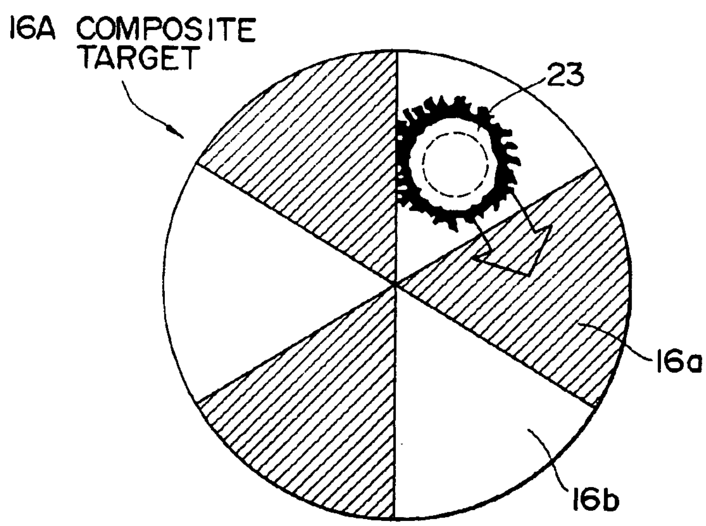
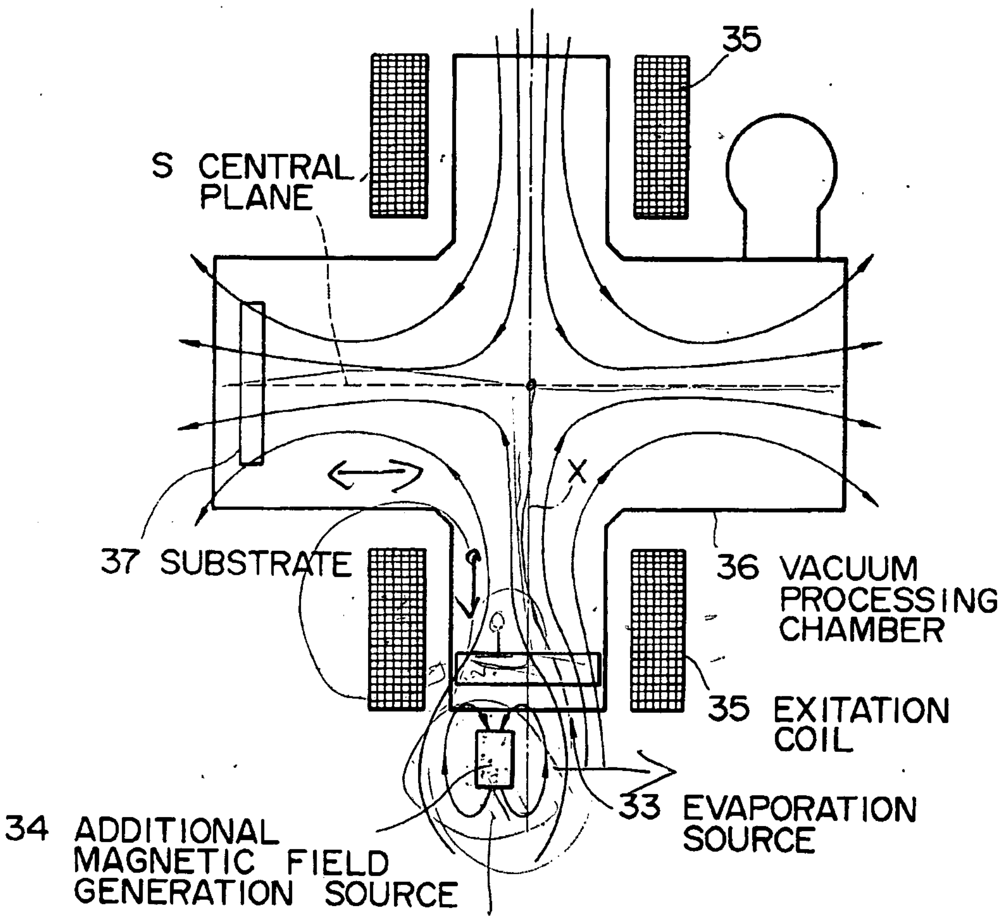

21
C
X
24
16
14
27
28
26
25
22
32 DRIVING MOTOR

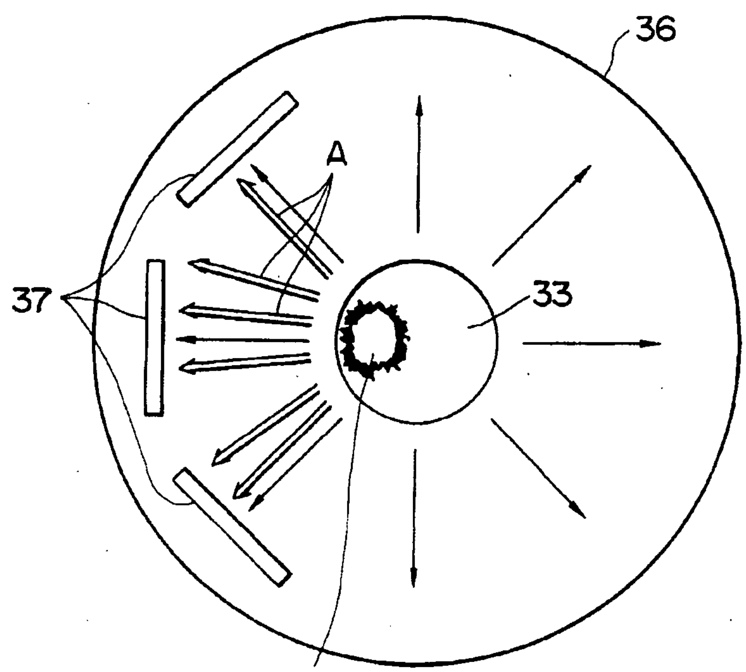
FIG. 7


16A COMPOSITE TARGET
23
16a
16b

F I G. 8


35
S CENTRAL PLANE
X
37 SUBSTRATE
36 VACUUM PROCESSING CHAMBER
35 EXITATION COIL
33 EVAPORATION SOURCE
34 ADDITIONAL MAGNETIC FIELD GENERATION SOURCE

F I G. 9



F I G. 10

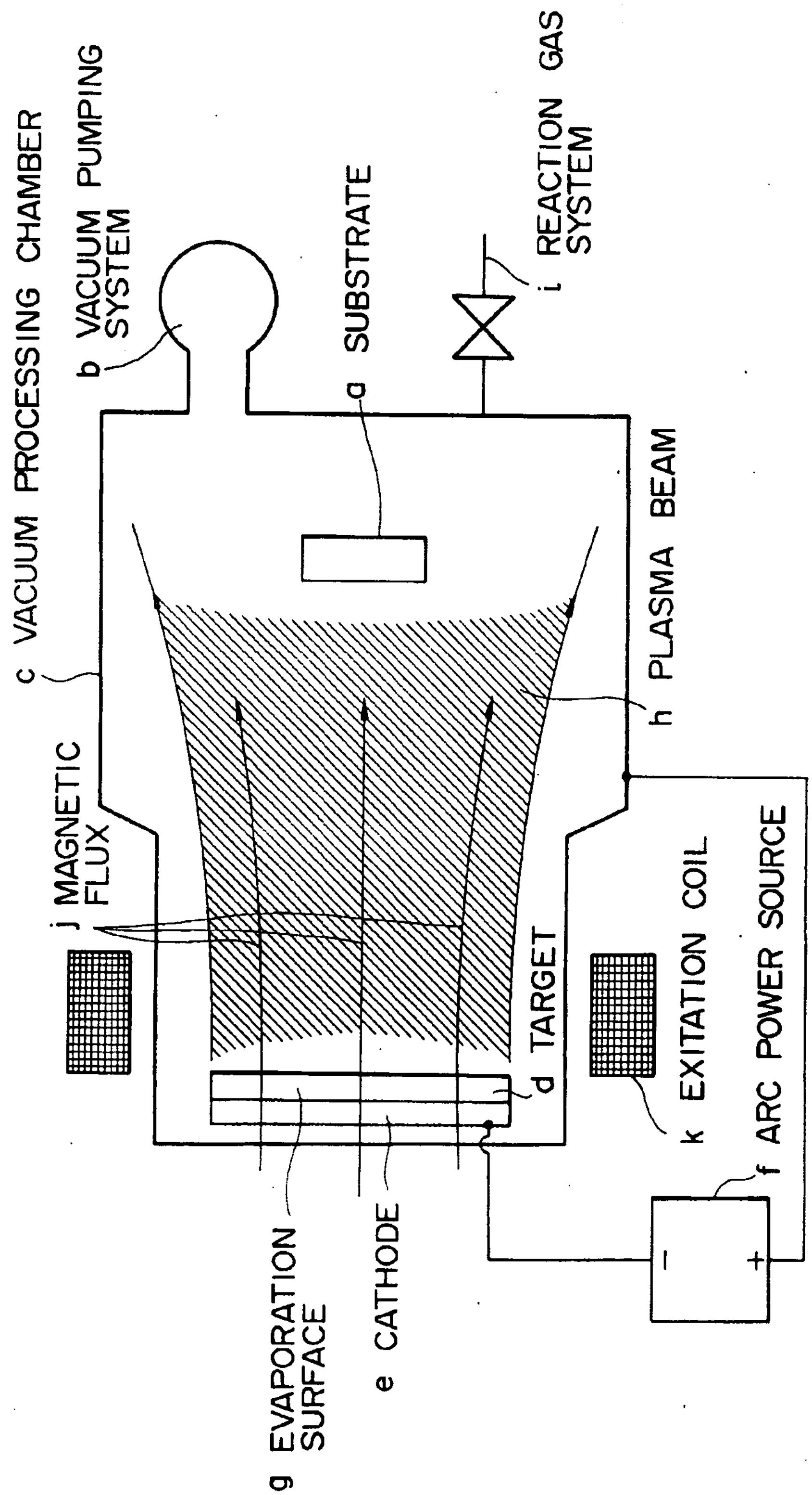
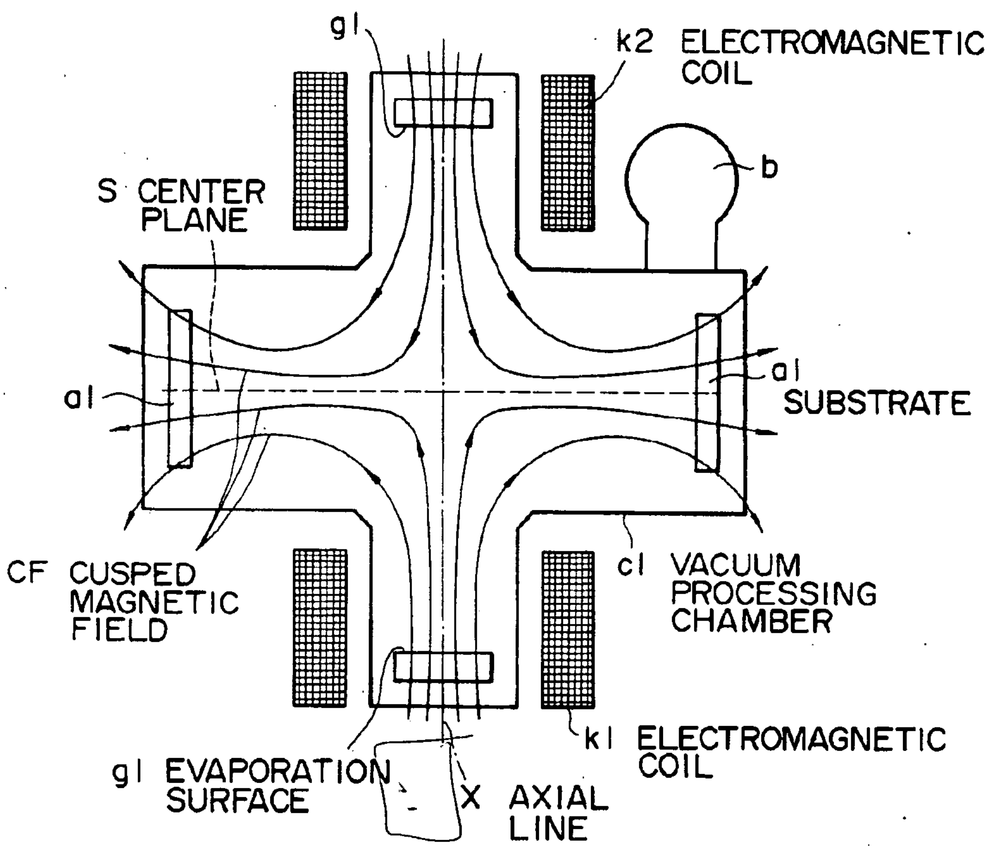

c VACUUM PROCESSING CHAMBER
b VACUUM PUMPING SYSTEM
a SUBSTRATE
i REACTION GAS SYSTEM
h PLASMA BEAM
j MAGNETIC FLUX
d TARGET
k EXITATION COIL
f ARC POWER SOURCE
g EVAPORATION SURFACE
e CATHODE
−
+

FIG. 11


g1
k2 ELECTROMAGNETIC COIL
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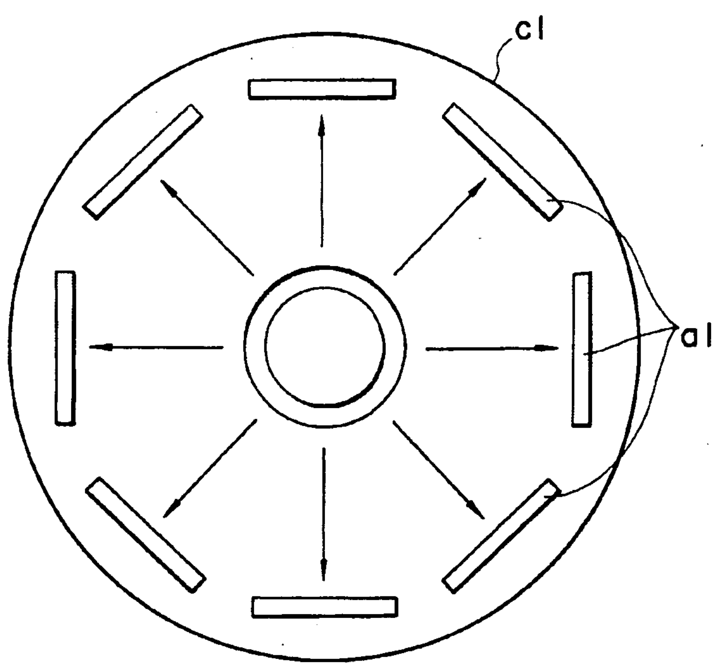
S CENTER PLANE
a1
a1 SUBSTRATE
CF CUSPED MAGNETIC FIELD
c1 VACUUM PROCESSING CHAMBER
k1 ELECTROMAGNETIC COIL
g1 EVAPORATION SURFACE
X AXIAL LINE

FIG. 12



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 10 0496

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X A	WO-A-8 705 948 (REGENTS OF THE UNIVERSITY OF MINNESOTA) * page 11, line 5 - page 12, line 11 * * page 15, line 30 - page 16, line 25 * * page 17, line 24 - page 18, line 10; figures 1,3,4,7 *	1-4,9,11 7,10,13	C23C14/32 H01J37/32
A	WO-A-8 901 699 (REGENTS OF THE UNIVERSITY OF MINNESOTA) * page 14, line 15 - line 32 * * page 17, line 25 - page 19, line 20; figures 8-14 *	1-13	
A	EP-A-0 283 095 (HAUZER HOLDING B.V.) * column 3, line 16 - line 53 *	10	
A,D	PATENT ABSTRACTS OF JAPAN vol. 14, no. 109 (C-695)(4052) 28 February 1990 & JP-A-1 312 067 (KOBE STEEL LTD) 15 December 1989 * abstract *	6,8	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

C23C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	01 APRIL 1992	EKHULT H.U.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

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APPLICATION NUMBER : 02240075

APPLICANT : ANELVA CORP;

INVENTOR : HIRATA KAZUO;

INT.CL. : C23C 14/35 C23C 14/08

TITLE : SPUTTERING DEVICE AND PRODUCTION OF FILM

ABSTRACT : PURPOSE: To reduce the absolute value of the self-bias voltage of the cathode and to prevent the resputtering of a film on a substrate by negative ions emitted from the cathode by arranging magnets generating a strong magnetic field near a target electrode and using halogen-contg. gas as part of gas to be introduced.

CONSTITUTION: When magnets are arranged near a target in a vacuum vessel and a thin oxide film is produced on a substrate by high-frequency sputtering of the target, halogen-contg. gas, preferably bromine or fluorine-contg. gas is used as part of gas to be introduced into the vessel. The absolute value of the self-bias voltage of the cathode can be reduced by negative halogen ions and the self-bias voltage of the cathode can be controlled by controlling the flow rate of the halogen-contg. gas. Magnets generating a strong magnetic field on the surface of the magnet are preferably arranged so that a component of the magnetic field parallel to the surface of the target becomes ≥400G at a position at which a component of the magnetic field perpendicular to the surface of the target becomes zero.

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⑤Int. Cl.⁵	識別記号	庁内整理番号	㊸公開　平成4年(1992)4月24日
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⑭発明の名称　スパツタリング装置および膜作製方法

㉑特　願　平2－240075
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明　細　書

1．発明の名称

スパッタリング装置および膜作製方法

2．特許請求の範囲

(1) ターゲットの近傍に磁石を配置した高周波スパッタリング装置において、

導入ガスの一部としてハロゲン系のガスを導入するガス導入部を有することを特徴とするスパッタリング装置。

(2) ターゲット表面において、ターゲット表面に垂直な磁界成分がゼロになる位置でのターゲット表面に平行な磁界成分が４００ガウス以上であることを特徴とする請求項１記載のスパッタリング装置。

(3) 被処理基体を保持する基体ホルダーに負電圧を印加する基体バイアス機構を有することを特徴とする請求項２記載のスパッタリング装置。

(4) ターゲットの近傍に磁石を配置して、前記ターゲットを高周波スパッタリングすることによって被処理基体上に酸化物薄膜を作製する膜作製方法において、

導入ガスの一部としてハロゲン系ガスを真空容器内に導入することを特徴とする膜作製方法。

(5) 前記ハロゲン系ガスとして臭素系ガスまたはフッ素系ガスを利用することを特徴とする請求項４記載の膜作製方法。

(6) 前記ハロゲン系ガスの流量を制御することによってカソードのセルフバイアス電圧を制御することを特徴とする請求項４記載の膜作製方法。

(7) ターゲット表面において、ターゲット表面に垂直な磁界成分がゼロになる位置でのターゲット表面に平行な磁界成分が４００ガウス以上であることを特徴とする請求項４記載の膜作製方法。

(8) 被処理基体を保持する基体ホルダーに負電圧を印加することを特徴とする請求項７記載の膜作製方法。

(9) カソードのセルフバイアス電圧よりも絶対値の小さい負電圧を前記基体ホルダーに印加することを特徴とする請求項８記載の膜作製方法。

3．発明の詳細な説明

［産業上の利用分野］

この発明は、ターゲットの近傍に磁石を配置して高周波スパッタリングを行うスパッタリング装置に関し、また、この装置を利用して酸化物薄膜を作製する膜作製方法に関する。

［従来の技術］

近年、スパッタリング現象を利用して薄膜を作製し、その薄膜の基礎物性を測定したり、薄膜を加工してデバイス等に応用する基礎研究や実用化技術の開発をしたりすることが活発に行われている。

スパッタリング現象は、ターゲットに高エネルギーイオンを入射させることにより、ターゲットからスパッタ粒子（中性粒子）を発生させ、基体上にスパッタ粒子を堆積させる現象である。

最近脚光を浴びている酸化物超電導体薄膜やＩＴＯ薄膜（透明導電膜）等もこのスパッタリング現象を利用して作製されている。しかし、これらの薄膜を作製する際に酸化物ターゲットをスパッタリングすると、次のような現象が起こることが報告されている。

(1) ターゲットに高エネルギーイオンを入射して、ターゲットから放出される２次イオンを分析すると、酸素の負イオンが主ピークとして検出される（第５０回応用物理学会学術講演会　講演予稿集　２８ａ－ＰＢ－１７，1989）。

(2) ターゲットから放出された負イオンは、ターゲット上のシース電界により基体方向に加速される。この負イオンはターゲットのセルフバイアス電圧による加速エネルギーとほぼ同等なエネルギーを持つ（第３７回応用物理学関係連合講演会　講演予稿集　２９ａ－Ｖ－９，1990）。

(3) カソードシース電界により加速された高エネルギー負イオンは基体表面を衝撃し、基体表面に付着しているスパッタ粒子（膜）を再スパッタリングする現象を起こす（第３７回応用物理学関係連合講演会　講演予稿集　２９ａ－Ｖ－８，1990）。

酸化物超電導体薄膜においては、この再スパッタリング現象により、その組成がターゲットの組成と一致しなくなり、その超電導特性が著しく劣化する。また、ＩＴＯ薄膜においても同様な原因により、その導電性が著しく劣化する。

この再スパッタリング現象は、負イオンがカソードシースの電界により高エネルギーを与えられることに起因するので、再スパッタリング現象を防止するには、カソードシースの電界を小さくすればよい。すなわち、高周波スパッタリングにおいて、カソードのセルフバイアス電圧の絶対値を小さくすればよい。このセルフバイアス電圧の値は次の条件に依存している。

(a) カソードのセルフバイアス電圧は、カソードに印加する高周波電力に依存する。つまり、電力が大きくなれば、セルフバイアス電圧の絶対値も大きくなる。第６図にセルフバイアス電圧と印加電力の関係を示す。

(b) カソードのセルフバイアス電圧は、真空容器内の圧力に依存する。つまり、圧力が高くなれば、セルフバイアス電圧の絶対値は小さくなる。第７図にセルフバイアス電圧と圧力の関係を示す。

(c) カソードのセルフバイアス電圧は、印加する高周波電力の周波数に依存する。つまり、周波数が高くなれば、セルフバイアス電圧の絶対値は小さくなる（参考文献：THE SECOND ISTEC WORKSHOP ON SUPERCONDUCTIVIY, MAY28-30, 1990, p.21）。

したがって、カソードに印加する電力や、真空容器内の圧力、印加電力の周波数を制御すれば、セルフバイアス電圧を制御できることになる。

［発明が解決しようとする課題］

しかし、これらの条件を制御するには次のような問題がある。

上述の(a)の電力制御には次のような問題がある。電力を低くするとセルフバイアス電圧の絶対値は小さくなる傾向にあるが、セルフバイアス電圧の絶対値を１００Ｖ以下にするには、印加電力を３０Ｗ以下にしなければならない。しかし、こうすると膜堆積速度が小さくなってしまう。また、

電力を０～３０Ｗの範囲内で変化させた場合は、セルフバイアス電圧が急激に変化してしまい、実用的には、精密にセルフバイアス電圧を制御することはできない。

上述の(b) の圧力制御には次のような問題がある。ガス圧力を高くするとセルフバイアス電圧の絶対値は低くなる傾向にあるが、セルフバイアス電圧の絶対値を１００Ｖ以下にするには、圧力を５００ｍTorr 以上にしなければならない。しかし、こうするとスパッタ粒子とガス粒子とが衝突して散乱を起こし、膜厚分布や膜組成分布の面内の変動が大きくなる。したがって、有効な膜の面積は小さくなってしまう。また、上述の(a) の場合と同様に極端に膜堆積速度が小さくなる傾向があり、実用的でない。

上述の(c) の周波数制御には次のような問題がある。周波数を１３．５６ＭＨｚから１００ＭＨｚに上昇させるとセルフバイアス電圧の絶対値は小さくなる傾向がある。しかし、上述の(c) で引用した文献に示されているように、周波数を１００ＭＨｚに上昇させたとしてもセルフバイアス電圧の絶対値は１００Ｖ以下にはならない。また、この文献から明らかなように、確かに膜組成の均一性は良好となるが、ターゲット組成と膜組成とが一致していない。これは、セルフバイアス電圧の絶対値が１００Ｖと高いために組成変動を起こしているからである。さらに、周波数を変化させるためには、発振器や、電源、インピーダンス整合器を変更する必要があり、非常に費用がかかる。また、周波数を高くすることにより浮遊容量の影響を受け、インピーダンスマッチングの調整等に非常に手間がかかる。

そこで、この発明の目的は、上に挙げた方法以外の方法によってセルフバイアス電圧を小さくすることのできるスパッタリング装置を提供することと、この装置を利用した膜作製方法を提供することにある。

［課題を解決するための手段］

第１の発明のスパッタリング装置は、ターゲットの近傍に磁石を配置した高周波スパッタリング装置において、

導入ガスの一部としてハロゲン系のガスを導入するガス導入部を有することを特徴としている。

第２の発明のスパッタリング装置は、第１の発明の特徴に加えて、ターゲット表面において、ターゲット表面に垂直な磁界成分がゼロになる位置でのターゲット表面に平行な磁界成分が４００ガウス以上であることを特徴としている。

第３の発明のスパッタリング装置は、第２の発明の特徴に加えて、被処理基体を保持する基体ホルダーに負電圧を印加する基体バイアス機構を有することを特徴としている。

第４の発明の膜作製方法は、ターゲットの近傍に磁石を配置して、前記ターゲットを高周波スパッタリングすることによって被処理基体上に酸化物薄膜を作製する膜作製方法において、

導入ガスの一部としてハロゲン系ガスを真空容器内に導入することを特徴としている。

第５の発明の膜作製方法は、第４の発明におけるハロゲン系ガスとして臭素系ガスまたはフッ素系ガスを利用することを特徴としている。

第６の発明の膜作製方法は、第４の発明におけるハロゲン系ガスの流量を制御することによってカソードのセルフバイアス電圧を制御することを特徴としている。

第７の発明の膜作製方法は、第４の発明の特徴に加えて、ターゲット表面において、ターゲット表面に垂直な磁界成分がゼロになる位置でのターゲット表面に平行な磁界成分が４００ガウス以上であることを特徴としている。

第８の発明の膜作製方法は、第７の発明の特徴に加えて、被処理基体を保持する基体ホルダーに負電圧を印加することを特徴としている。

第９の発明の膜作製方法は、第８の発明において、カソードのセルフバイアス電圧よりも絶対値の小さい負電圧を前記基体ホルダーに印加することを特徴としている。

［作用］

導入ガスの一部にハロゲン系のガスを利用すると、プラズマ中にハロゲンの負イオン（例えば

Br⁻、F⁻）を生じる。この負イオンは、カソードのセルフバイアス電圧の絶対値を低下させるように作用する。ハロゲン系のガスの流量を制御すると、プラズマ中のハロゲンの負イオンの量を制御できるので、カソードのセルフバイアス電圧を精密に制御できる。セルフバイアス電圧を精密に制御できると、膜堆積速度を精密に制御することができる。

ターゲット表面に磁界を形成してプラズマ密度を高める、いわゆるマグネトロンスパッタリングにおいては、磁界がターゲット表面に平行になる位置、すなわちターゲット表面に垂直な磁界成分（以下、Bvという。）がゼロになる位置で、プラズマ密度が高くなる。そして、このBvがゼロになる位置での、ターゲット表面に平行な磁界成分（以下、Bhという。）が大きければ大きいほどプラズマ密度が高くなり、それに伴ってカソードのセルフバイアス電圧の絶対値が小さくなる。好ましくはセルフバイアス電圧の絶対値が100V以下になるようにする。この発明では、Bhが400ガウス以上となるようにしている。このような大きな磁界を得るには希土類磁石を利用するとよい。なお、マグネトロンスパッタリング用の通常の磁石では、Bhは250ガウス程度である。

以上のように、ハロゲン系のガスを利用したり、大きな磁界を利用したりすることによって、カソードのセルフバイアス電圧の絶対値を小さくすることができる。その結果、ターゲットから放出される負イオンの加速エネルギーを小さくすることができて、この負イオンによる基体への衝撃を緩和することができる。

さらに、基体ホルダーの側でも上述の負イオン衝撃を緩和するための工夫をすることができる。すなわち、基体ホルダーに負電圧を印加することによって負イオン衝撃を緩和することができる。基体ホルダーに印加する負電圧は、カソードのセルフバイアス電圧よりも絶対値が小さくなるようにしている。

［実施例］

次に、図面を参照してこの発明の実施例を説明する。

第1図は、この発明のスパッタリング装置の一実施例の正面断面図である。真空容器1は矢印6方向に設置してある主排気系で排気できて10^{-7} Torr 以下の圧力に保つことができる。真空容器1には、薄膜を作製するために必要なガスを供給するためのガス導入系29を設け、バルブ23、24、25を介して真空容器1の中へガスを導入できるようにしている。例えば、矢印10方向からArガス、矢印11方向からO_2ガス、矢印12方向からBr_2ガスを導入し、これらを混合して真空容器1の中へ導入する。真空容器1内の圧力は、ガス導入系29のマスフローメータ（図示せず）と、矢印6方向に設置してある主排気系とを調節することにより、適切な値に設定できる。真空容器1内には、基体14を保持してこれを800℃まで加熱することができる基体ホルダー13を設置している。加熱方式は、温調計19とサイリスタユニット18と基体ホルダー13の表面に取り付けた熱電対26とによりランプヒータ15を制御する方式である。

基体ホルダー13は絶縁石17によって真空容器1に対して電気的に絶縁されている。基体ホルダー13はリード線16によって真空容器1の外にあるバイアス電源20に接続されている。このバイアス電源20はバイポーラ方式の電源で、正の電圧と負の電圧のいずれかを選択して基体ホルダー13に印加できる。基体ホルダー13にバイアス電圧を印加することにより、ターゲットから基体に入射する負イオンのエネルギーを制御することができる。

基体ホルダー13に対向する位置にはターゲットシールド2を設置し、このターゲットシールド2の内側に絶縁リング8（フッ素樹脂製）を介してターゲット3とカソードボディ30を設置している。このカソードボディ30には冷却水（矢印9a、9b）を流して冷却している。また、カソードボディ30にはインピーダンス整合器21、高周波電源22が接続している。この高周波電源22によりカソードボディ30に電力を供給して

いる。

カソードボディ30の中には希土類磁石で構成した円筒形の高磁界磁石7を収納している。第2図は高磁界磁石7の正面断面図である。この高磁界磁石7は磁界4を発生し、ターゲット3の表面において、ターゲット3の表面に垂直な磁界成分Bvがゼロになる位置で、ターゲット3の表面に平行な磁界成分Bhが1200ガウスとなる磁界強度を持っている。

第1図に戻って、カソードボディ30にはローパスフィルタ27を介して電圧計28を接続している。カソードボディ30に高周波電力を印加すると、真空容器1内で放電が生じたときにカソードボディ30にセルフバイアス電圧が誘起される。このセルフバイアス電圧Vsを電圧計28によってモニターする。

高周波電力＝150W、圧力＝25mTorr のときの、Bv＝0の位置での磁界成分Bhとセルフバイアス電圧Vsとの関係を第3図に示す。Bh＝0すなわち磁石がない場合は、Vs＝－933Vである。磁界成分Bhを大きくすると、セルフバイアス電圧Vsの絶対値は急激に減少する。Bh＝1200ガウスのときは、Vs＝－70Vとなる。このように磁界成分Bhを大きくすることによりセルフバイアス電圧Vsの絶対値を低下させることができる。ただし、高磁界磁石7は永久磁石であるため、いったん磁石を設置してしまうと磁石によってセルフバイアス電圧Vsを制御することはできない。すなわち、磁石の選択によって大まかには磁石強度を設定できるが、精密にBhを制御するには別の工夫が必要となる。

そこで、この実施例においては、ハロゲン系のガスの導入によってセルフバイアス電圧Vsの精密な制御を行っている。この実施例では、ガス導入系29において、臭素ガス（Br_2）をマスフロメーター（図示せず）とバルブ25を介して真空容器1内に導入している。このときのセルフバイアス電圧Vsと、Br_2ガスの分圧比「Br_2／（$Ar+O_2+Br_2$）」との関係を第4図に示す。Br_2ガスの分圧比を増加させることによりセルフバイアス電圧Vsの絶対値を低下させることができる。したがって、高周波電力と真空容器内の圧力を一定にしておいて、Br_2ガスの分圧比を調節することにより、セルフバイアス電圧Vsを精密に制御することができる。

スパッタリングによる膜堆積速度はセルフバイアス電圧に依存するので、セルフバイアス電圧を精密に制御できるようになると、これによって膜堆積速度を精密に制御することができる。特に、マルチカソードスパッタリングによって超格子薄膜を数オングストロームずつ積層していくような場合には、膜堆積速度を精密に制御する必要があり、セルフバイアス電圧の精密制御はこのような場合に有効である。

第4図から明らかなように、Br_2ガスの分圧比が大きくなるほどセルフバイアス電圧の絶対値は低下するが、Br_2ガスは腐食性が強いので、あまり分圧比を大きくするとガス導入系やチャンバ内が腐食によって汚染される恐れがある。したがって、Br_2ガスの分圧比は0．1程度に抑えるのが好ましい。

セルフバイアス電圧の絶対値を小さくすることは基体への負イオン衝撃を緩和する上で重要であるが、セルフバイアス電圧の絶対値を小さくし過ぎると膜堆積速度が小さくなり過ぎて実用的でない。そこで、セルフバイアス電圧の絶対値は50V以下にならないようにするのが好ましい。

次に、このスパッタリング装置を用いて酸化物薄膜を作製する方法について説明する。

ターゲットから負イオンが発生する物質の一例として、酸化物超電導体$Y_1Ba_2Cu_3O_y$がある。そこで、ターゲット3として、直径4インチの$Y_1Ba_2Cu_3O_y$焼結体ターゲットを用いる。第1図のガス導入系29において、バルブ23、24とマスフロメータ（図示せず）を介して、矢印10方向からArガスを、矢印11方向からO_2ガスを供給し、これらを混合して真空容器1の中へ導入する。このときのArガスとO_2ガスとの混合比は1対1である。真空容器1内の圧力は25mTorr にする。ターゲット3と基体

ホルダー１３との間隔は２５ｍｍである。ターゲット３の近傍には高磁界磁石７により高磁界が形成されている。すなわち、ターゲット表面において、磁界成分Ｂｖがゼロになる位置で、磁界成分Ｂｈが１２００ガウスとなっている。ターゲット３には、高周波電源２２から１３．５６ＭＨｚの周波数で１５０Ｗの高周波電力を印加し、インピーダンス整合器２１により、反射波が０Ｗ（ゼロワット）になるように調整している。このとき、フィルター２７を介して電圧計２８によってモニターしたセルフバイアス電圧Ｖｓは－７０Ｖであった。

セルフバイアス電圧Ｖｓをさらに下げるために、矢印１２方向からマスフロメーター（図示せず）を介して真空容器１内にBr_2ガスを導入した。そして、真空容器内の圧力が２５ｍTorr になるようにＡｒガス、O_2ガス、Br_2ガスの各流量を調整し、Br_2ガスの分圧比「Br_2／（Ａｒ＋O_2＋Br_2）」が０．１になるようにした。このときのセルフバイアス電圧Ｖｓは－５０Ｖとなった。

ａｓ－ｇｒｏｗｎ状態で超電導特性を得るために、基体１４を６００～７００℃に加熱した状態で、上記の条件で薄膜を堆積させた。基体１４にはＭｇＯ（１００）を用いて、Ｃ軸配向の膜を得た。そして、この膜が再現性よく得られることを確認した後、基体バイアス電圧の影響を調べた。すなわち、バイアス電源２０によって基体１４に負のバイアス電圧を印加し、バイアス電圧の値をいろいろに変えて超電導体薄膜を作製した。その結果、バイアス電圧Ｖｂが－１０Ｖのときに最も良好な特性を有する膜を得た。

第５図に基体上の膜の組成比分布を示す。（ａ）は実施例の場合を、（ｂ）は従来例の場合を示している。以下に、実施例と従来例を比較して示す。

（ａ）実施例

(1) 組成比の変動が±５％以内の均一膜組成領域：直径１００ｍｍ以内

(2) 膜の超電導臨界温度：９０Ｋ

(3) セルフバイアス電圧：－５０Ｖ

（ｂ）従来例

(1) 組成比の変動が±５％以内の均一膜組成領域：直径４５ｍｍ以内

(2) 膜の超電導臨界温度：８２Ｋ

(3) セルフバイアス電圧：－１８２Ｖ

実施例においては高磁界磁石を利用することによりセルフバイアス電圧を低下させ、さらに、Br_2ガスの流量を制御することによりセルフバイアス電圧を精密に制御した。その結果、実施例と従来例とを比較すると、実施例では膜組成が改善され、特に、均一膜組成領域は従来例の４倍以上の面積になった。また、膜中には、Ｙ、Ｂａ、Ｃｕ、Ｏのほかに Ｂｒ のピークが見られたが、Ｂｒが超電導特性を劣化させることはない。なお、上述の従来例は、標準磁石を利用し、Br_2ガスを導入せずに、基体バイアスも印加しない条件で膜作成を行ったものである。

Ｂｒガスの他に以下に示す臭素系ガス、フッ素系ガスを用いても、上記と同様な膜を得ることができる。すなわち、Ｂｒ系ガスとしては、BBr_3、ＨＢｒ、BrF_3、BrF_5、$CBrF_3$、$C_2Br_2F_4$、CH_3Brを用いることができる。また、フッ素系ガスとしては、NF_3、BF_3、SF_4、SF_6、CF_4、ＨＦ、ClF_3、C_2F_6、C_3F_8、CH_3Fを用いることができる。

なお、この実施例においてはターゲット材料として酸化物超電導体を用いたが、ターゲットから負イオンが放出されるようなその他の酸化物をターゲットに使う場合にも、同様な効果が得られる。

［発明の効果］

この発明によれば次のような効果が得られる。

(1) ターゲット電極の近傍に高磁界磁石を設置することにより、カソードのセルフバイアス電圧の絶対値を小さくできる。

(2) 導入ガスの一部にハロゲン系ガスを使うことにより、カソードのセルフバイアス電圧の絶対値を小さくすることができる。さらに、このハロゲン系ガスの流量を制御することによりカソードのセルフバイアス電圧を精密に制御できる。

(3) 以上のようにカソードのセルフバイアス電圧の絶対値を小さくすることにより、カソードから放出された負イオンによる基体上の膜の再スパッタリングを防止できる。

(4) 被処理基体に負のバイアス電圧をかけることにより、基体に入射する負イオンの入射エネルギーを制御することができる。その結果、負イオンの入射エネルギーを適当な値に低下させることができて、基体表面上でのスパッタ粒子と負イオンとの化学反応を促進させ、酸化物膜の膜質や結晶構造を良好なものにできる。

4. 図面の簡単な説明

第1図はこの発明のスパッタリング装置の一実施例の正面断面図、

第2図は高磁界磁石の正面断面図、

第3図は磁界の強さとセルフバイアス電圧との関係を示すグラフ、

第4図はセルフバイアス電圧と臭素ガスの分圧比の関係を示すグラフ、

第5図は基体上の膜の組成比分布を示すグラフ、

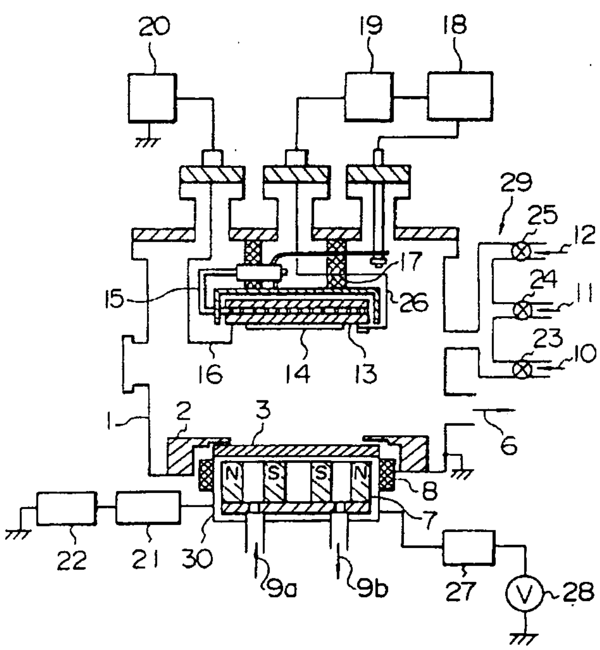
第6図はカソードのセルフバイアス電圧と印加電力の関係を示すグラフ、

第7図はカソードのセルフバイアス電圧と真空容器内圧力の関係を示すグラフである。

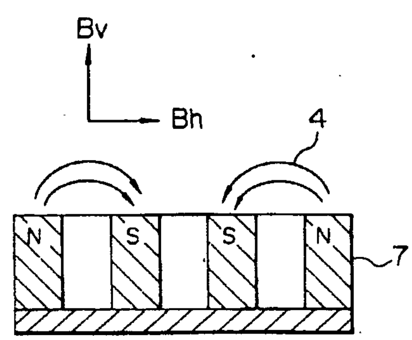
1…真空容器
3…ターゲット
7…高磁界磁石
13…基体ホルダー
14…基体
20…基体バイアス電源
22…高周波電源
29…ガス導入系
30…カソードボディ

代理人 弁理士 鈴木 利之

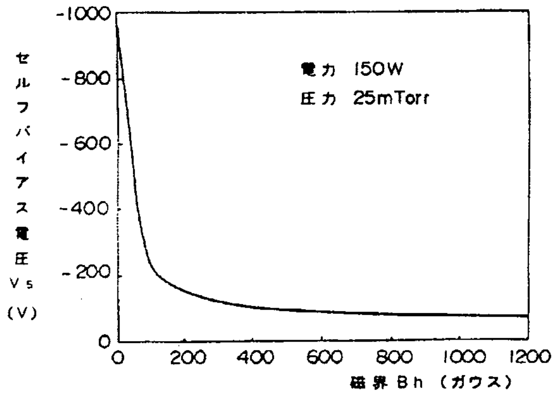
1：真空容器　20：基体バイアス電源
3：ターゲット　22：高周波電源
7：高磁界磁石　29：ガス導入系
13：基体ホルダー　30：カソードボディ



第1図



第2図



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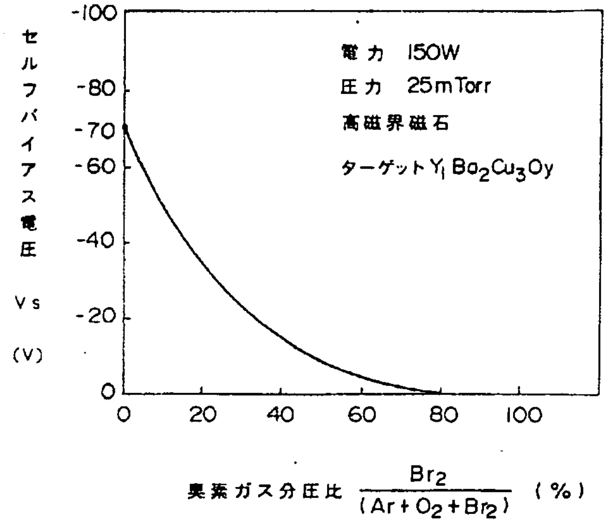

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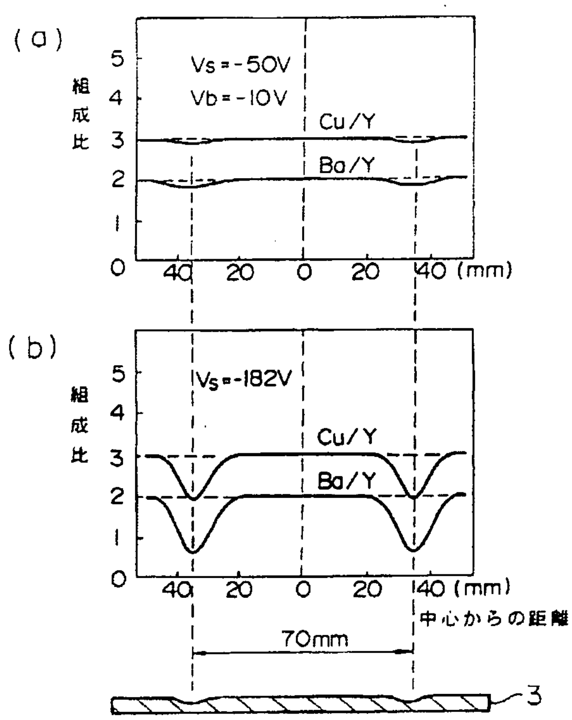

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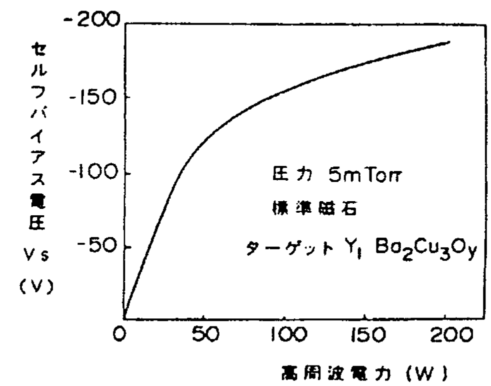
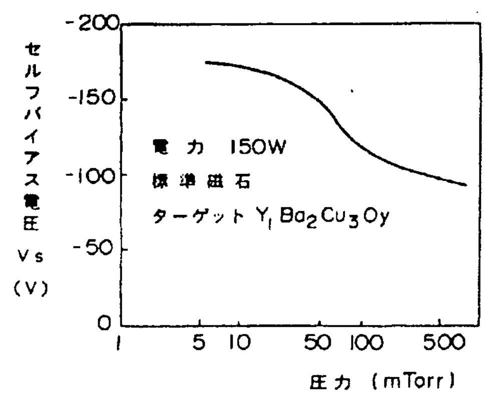


第 6 図



第 7 図

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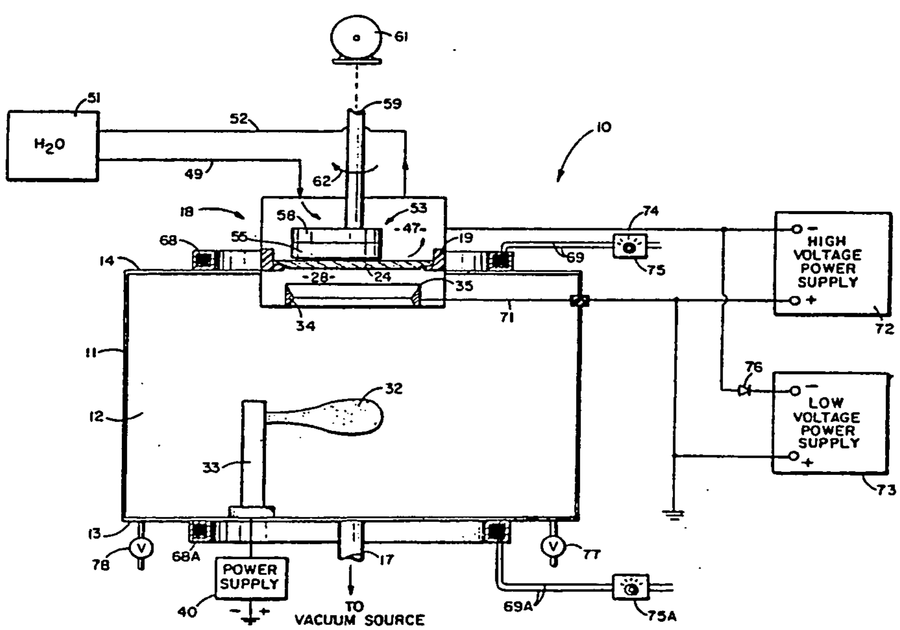

(57) Abstract

A method and apparatus for vacuum arc deposition of material on a surface of an object (32), uses a vacuum chamber (12) accomodating the active surface of the cathode (24) and an anode (34). A power supply connected to the anode (34) and cathode (24) establishes an electric arc. The track of the arc is controlled with a magnetic field established with a permanent magnet (56) that is moved in a closed path relative to the cathode. A solenoid (68) modifies the main magnetic field produced on the active surface of the cathode (24).

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CONTROLLED VACUUM ARC MATERIAL DEPOSITION, METHOD AND APPARATUS

FIELD OF INVENTION

This invention relates to processes and apparatus for applying coatings by the deposition of material evaporated by an electric arc in a vacuum.

BACKGROUND OF THE INVENTION

Vacuum arc processes have been used in the preparation of pure high melting point metals. A by-product of this process is a thin metal film on the walls of the vacuum chamber. Lucas et al in the publication "A New Deposition Technique for Refractory Metal Films", American Vacuum Society Transactions 2, 1962, p. 988-991, describe a vacuum arc deposition technique to produce refractory metal films, such as noibium, tantalum, vanadium and iron films. This technique used an electric motor or hand lever to mechanically ignite the vacuum arc. The current flowing between an anode and a cathode electrode was interrupted by rapidly withdrawing the movable electrode a short distance from the stationary electrode. The short arc produced between the electrodes yields a vapor flux. This vapor flux condensed on a substrate to produce a metal film.

An electric arc ignited between a cathode and an anode in a vacuum generates cathode sports. Currents of a few amperes to a few hundred amperes yield intense cathode spots and diffuse anode spots. Typically, arcs are sustained in vacuum at anode-cathode potential differences of 10 to 25 volts or more. Arc sustaining voltage is a function of material properties. Substantial power is dissipated in an arc column. For an arc current of 100 amperes and a voltage of 20 volts, power

dissipation is 2 KW. In such an arc column, more than half of the arc power is dissipated at the cathode. A large part of the remainder is dissipated at the anode.

Intense cathode spots produced are very small in size. Current density at the cathode spot is of the order of 10^5 to 10^7 amperes per square cm. The arc duration at a cathode spot usually varies between a few to several thousand micro-seconds. High local temperatures are produced due to high current densities. Cathode spot temperatures approximately equal the boiling point of the material making up the cathode. Due to this high temperature, substantial vapor pressures are developed by vacuum arcs. The vapors produced by cathode spots are used to coat objects placed within the vacuum chamber and to sustain the arc ignited between the cathode and an anode.

Snaper in U.S. Patent No. 3,625,848 discloses an apparatus for coating an object with a thin film of source material with the use of a vacuum arc. A beam of source atoms and ions is directed at a base or substrate to be coated within a vacuum chamber. The beam gun has a cathode and an anode arranged to sustain an arc discharge. Current flow between the cathode and an igniter electrode attached to a permanent magnet is interrupted to ignite the arc. This is accomplished by passing the current through a solenoidal coil located outside the vacuum chamber. The solenoidal coil field interacts with the permanent magnet connected to the igniter electrode to interrupt current flow in the cathode igniter circuit. This current flow interruption produces a short arc which is sustained between the main anode and cathode. The magnetic field of the solenoid also modifies the operating characteristics of the gun and increases the arc potential between the cathode and anode.

Sablev et al in U.S. Patent No. 3,793,179 disclose an apparatus for metal evaporation coating. The apparatus embodies a mechanical arc igniter between

a disk cathode and a hollow spherical anode. A solenoid armature and an igniter circuit is incorporated in the main arc circuit in such a manner as to automatically re-ignite the arc whenever it extinguishes. The arc once produced is free to move at random at high speed over the cathode surface. Arc spot motion is chaotic and uncontrolled. Periodically, arc spots will pass the edge of the cathode. This extinguishes the arc.

Rapidly moving, short-lived arc spots darting across the cathode surface generate vapor as well as discrete metal particles. Solid metal particles deposited on objects degrade their surface finish and the quality of the coated film. In many applications, such as thin film devices, recording media, optical coatings and tribological coatings, the presence of micron-size solid particles is unacceptable.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for applying material by vacuum arc deposition onto the surface of an object or part located in a vacuum chamber. A power supply electrically coupled to the anode and cathode is operable to sustain an electric arc between the active surface of the cathode and the anode. Means are provided to control and direct the path of the arc produced on the active surface of the cathode. The arc is made to travel repeatedly over the same track to provide for vapor production of the material. Production of discrete particles of the material is eliminated in material having higher melting temperature and greatly reduced in other materials. The arc being directed to travel along a pre-selected track is not free to wander off the cathode active surface. This obviates the need for automatic re-ignition. The control over the arc track is obtained by generating a magnetic field with field vectors either completely or substantially parallel to the active surface of the

cathode. The arc column is generally perpendicular to the active surface of the cathode and the applied magnetic field is parallel to the active surface of the cathode which generates a Hall force that acts on the ions as well as the electrons in the vicinity of the cathode. The Hall force leads to cycloidal motion of electrons and massive ions move in the opposite direction. As they move under the influence of the applied magnetic field, the ions are also subject to the prevailing electric field. They are attracted to the active surface of the cathode. Sufficient number of ions impinging on the active surface of the cathode in the vicinity of the original cathode spot at a location consistent with the prevailing electric and magnetic fields induce intense local heating and electron emission in order to render this spot the new cathode spot. The presence of a local magnetic field appropriately disposed at this location can in turn lead to the generation of the next new cathode spot. The chaotic sequence of arc spots on the cathode surface of the prior arc deposition devices is replaced with an orderly sequence where all permitted cathode spots lie on a preselected track. This enables control over arc motion on the active surface of the cathode and eliminates periodic arc quenching due to chaotic arc motion beyond the cathode edge.

In one embodiment of the invention, the apparatus has a housing means defining a vacuum chamber accommodating the anode. A head mounted on the housing means supports the cathode. The cathode has an active surface located in the vacuum chamber spaced from the anode. Two power supplies coupled to the anode and cathode generate and sustain an electric arc between the active surface of the cathode and the anode. Magnet means, such as a permanent magnet, located adjacent the cathode establishes a magnetic field to control and direct the path of movement of the arc along a defined closed track

such as a circle produced on the active surface of the cathode. The magnet means is movably mounted on the head for controlled movement. The movement of the magnet means causes the arc track defined by the magnet means to sweep the active surface of the cathode. The magnetic field of a solenoidal coil or Helmholtz coil system is superpositioned on the magnetic field of the magnet means to modify the magnetic field produced on the active surface of the cathode by the magnet means. The direction of the current through the coil is chosen to either reinforce or reduce the magnetic strength normal to the active surface of the cathode. The solenoidal coil or Helmholtz coil system provides additional control over the arc path defined by the magnet means on the active surface of the cathode. This enables the generation of a magnetic field on the active surface of the cathode with a field more closely parallel to the active surface of the cathode than the field obtained solely with the magnet means.

The head is provided with a cooling chamber accommodating the magnetic means. The magnetic means is supported in the cooling chamber adjacent the cathode and moves or sweeps relative to the cathode according to predetermined movements such as circular, rectangular, oscillatory, or combinations of these movements whereby the arc is moved in a continuous controlled arc track. A cooling fluid, such as water, is continuously moved through the cooling chamber to provide an efficient and controlled cooling of the cathode.

The invention embodies a method of vacuum arc deposition of material on the surface of an object or part. A vacuum is established in a chamber accommodating an anode and the active surface of the cathode. Electrical potential from two power supplies is supplied to the anode and the cathode to ignite and maintain an electric arc between the anode and the cathode. The track of the arc is defined by a magnetic field estab-

lished with magnet means relative to the active surface of the cathode. The magnet means is moved relative to the cathode to sweep the active surface of the cathode with the arc track defined by the magnet means. The magnetic field can be modified with a solenoid generated magnetic field to selectively reinforce or reduce the magnetic field strength normal to the active surface of the cathode. The solenoid can be controlled to generate a desired magnetic field that controls the movement of the arc in a continuous arc track.

The method and apparatus for vacuum arc deposition of material is used to metallize semi-conductors and fabricate integrated circuits. Other utilizations include the deposition of recording media, optical coatings, optical storage media, protective coatings, and tool coatings. The coating materials can be metals, ceramics, carbon, silicon, and the like. Coatings can also be applied to polymer films. The films can be continuously moved to apply a continuous coating on the surface of the films. The fabrication of modulated micro structures, including metal-matrix composites can be accomplished.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an elevational view, partly sectioned, of the controlled vacuum arc material deposition apparatus of the invention;

Figure 2 is a sectional view taken along the line 2-2 of Figure 1;

Figure 3 is an enlarged sectional view taken along the line 3-3 of Figure 2 showing the material deposition head;

Figure 4 is a sectional view taken along the line 4-4 of Figure 3;

Figure 5 is a schematic view showing the controlled vacuum arc deposition apparatus and cooling and power supplies therefor;

Figure 6 is a diagram showing ion motion in a

plane perpendicular to the magnetic field;

Figure 7 is a diagram showing the order of arc spot sequence along the closed arc path on the active surface of the cathode;

Figure 8 is a diagram of a circular closed arc track achieved by the material deposition head;

Figure 9 is a diagram of a first modification of the closed arc track;

Figure 10 is a diagram of a second modification of the closed arc track;

Figure 11 is a side view of a modification of the controlled vacuum arc material deposition apparatus of the invention; and

Figure 12 is a sectional view taken along the line 12-12 of Figure 11.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, there is shown the controlled vacuum arc material deposition apparatus 10 of the invention. The apparatus 10 has a housing 11 enclosing a vacuum chamber 12. Housing 11 includes a generally flat bottom wall 13 and a flat top wall 14. A vacuum source 16 coupled to bottom wall 13 with a tubular member or hose 17 is operable to maintain a vacuum in chamber 12. Chamber 12 is evacuated to pressures from below 10^{-6} to 10^{-1} mm of Hg.

A material deposition head indicated generally at 18 is mounted on top wall 14. Head 18 can be mounted on the side wall of the housing. The head can be located entirely within the vacuum chamber 12. Referring to Figure 3, head 18 has an annular body 19 provided with an inwardly directed annular shoulder 21. The body 19 is an electrical insulation ring seated in a circular recess 22 in top wall 14. An O-ring 23 located in a groove in top wall 14 maintains a sealing relationship between body 19 and top wall 14. A disk cathode or target 24 has an outwardly directed annular lip 26 located on shoulder 21. The cathode 24 is metal, alloy,

carbon or other material that coats an object 32, such as a turbine blade. An electrical insulator support 33 attached to bottom wall 13 locates object in vacuum chamber 12. Other types of supports can be used to hold the object in vacuum chamber. Other types of objects, parts, films, and the like, can be coated with the material of cathode 24 in vacuum chamber 12. The inside or active surface 27 of cathode 24 extends over a circular opening 28 in top wall 14. Active surface 27 is in vacuum chamber 12. A metal sleeve 29 is located in an annular recess 31 in wall 14 surrounding opening 28. The upper edge of sleeve 29 engages shoulder 21 with a gap between sleeve 29 and body 19. Metal sleeve 29 shields the insulation body 19 to prevent an electrical short between the cathode-anode by the deposition of coating flux on the inner cylindrical surface of body 19.

A ring or annular anode 34 extended into opening 28 is mounted on top wall 14 with a plurality of electrical insulation blocks 36, 37 and 38. Other means can be used to support anode 34 on housing 11. The anode may be alternately placed generally within the vacuum chamber 12, below top wall 14 and parallel to the bottom surface of top wall 14. Anode 34 has a circular sharp edge 35 facing cathode 24 and an outer cylindrical surface 39 spaced inwardly from annular metal sleeve 29. Edge 35 is formed by the acute angle shape in cross section of anode 34. The sharp edge 35 results in less coating on anode 34. The cross sectional shape of the ring anode is generally triangular. The lower side of the triangle is truncated. The lower part of anode 34 tapers downwardly and outwardly to minimize interference with the passage of flux through the center opening of anode 34. Sharp edge 35 and annular or ring shape of anode 34 also aids in arc ignition at relatively low voltage.

A cathode carrier 41, made of conducting material,

telescopes into body 19 and retains disk cathode 24 on shoulder 21. Carrier 41 accommodates a first seal or O-ring 42 engageable with body 19 and a second seal or O-ring 43 engageable with the top of disk cathode 24. Carrier 41 has an internal chamber 47 accommodating a cooling liquid 48, such as water. A liquid supply line 49 carries liquid from a supply source 51, shown in Figure 5, such as a pump, to chamber 47. A liquid return line 52 connected to carrier 41 carries the liquid back to liquid source 51. The liquid is continuously moving through chamber 47 to cool disk cathode 24.

A magnet apparatus indicated generally at 53 is located in chamber 47. Magnet apparatus 53 is operable to generate a magnetic field with field vectors substantially parallel to the active surface 27 of cathode 24. Magnet apparatus has an inverted cup-shape member or pole 54 having an open end facing disk cathode 24. Member 54 is a soft magnetic structure having a cylindrical flange 55 located in close relation to the upper or outside surface of cathode 24. A cylindrical disk magnet member or pole 56 is attached to the top of member 54. The outer surface of magnet member 56 is spaced from the annular sidewall of the cup-shaped member 54 by an annular gap or space 57. The cup-shaped member 54 is attached to an electrical insulator or mounting plate 58. A rotatable shaft 59 projects into chamber 47 and is secured to mounting plate 58. Shaft 59 rotatably supports mounting plate 58 and magnet apparatus 53 in the chamber 47 and locates the magnet apparatus in contiguous relationship relative to disk cathode 24. A variable speed electric motor 61, shown in Figure 5, drivably connected to shaft 59 is operable to rotate the shaft as indicated by arrow 62 about the shaft axis 63. Shaft 59 is mounted in a sleeve bearing assembly 64 attached to top member 41. Magnet apparatus 53 has a magnetic axis 66 offset from shaft axis 63 whereby on rotation of shaft 59 by motor 61 the magnet apparatus

53 is moved in a continuous circular path. The circular path is illustrated at 60 in Figure 4. The axis 66 is the symmetrical axis of magnet apparatus 53. Axis 66 is parallel to and offset from rotational axis 63. This arrangement enables the sweeping of the arc track 60 defined by magnet means so that the arc sweeps the area between an inner circle 65 and an outer circle 70 of the active surface 27 of cathode 24. The active surface 27 of the cathode 24 is the coating flux producing surface. Magnet apparatus can be a rectangular bar permanent magnet rotated about central axis 63 to cause the arc to sweep the active surface of the cathode 24 in a continuous predetermined rectangular path. Other shapes of the magnet apparatus and appropriate choices of rotational axes can be used to define arc tracks and to cause these arc tracks to sweep the active surface 27 of the cathode 24. Electric coil magnet structure can be used in lieu of the permanent magnet apparatus to establish the desired magnetic field to control the arc path.

Bearing assembly 64 seals water cooling chamber 47 without inhibiting the rotary motion of shaft 59. Water enters cooling chamber 47 via line 49 and exits chamber 47 via line 52. Adjusting the rate of flow of the water through chamber 47 produces an efficient and controlled cooling of the rear surface of cathode 24. The rotation of the magnet apparatus 53 circulates the liquid in chamber 47 and aids the cooling of cathode 24.

An electrical coil or winding 68 is mounted on top wall 14 concentric with shaft axis 63. Coil 68 surrounds head 18 and is located generally in the plane of cathode 27. Coil 68 is a solenoidal coil operable to cancel out or greatly reduce the vertical magnetic field component of magnet apparatus 53, and generate a purely parallel magnetic field on the active surface of the cathode 24. The superposition of the coil field on the magnet field of magnet apparatus 53 results in tighter control over

the arc track 60. Lines 69 connect coil 68 to a control 75, shown in Figure 5, and a source of electric power. Control 75 can be a manual current control device or computer controller that can be programmed to regulate the power to coil 68. A current passing through coil 68 modifies the main magnetic field produced on the active surface 27 of cathode 24 by magnet apparatus 53. The direction of the current through coil 68 is chosen to reinforce or reduce the magnetic field strength normal to the cathode active surface 27 of cathode 24. The magnetic field of magnet apparatus 53 has a component normal to the cathode active surface 27. This field component can be cancelled out or greatly reduced or can be increased by the superposition of a magnetic field generated by solenoid 68. This results in a tighter control over the arc track.

A second coil 68A is mounted on bottom wall 13 in axial alignment with coil 68. Lines 69A connect coil 68A to control 75 or control 75A and a power supply. Coils 68 and 68A may be concurrently used as a Helmholtz coil system to modify the magnetic field produced on the active surface of the cathode 24. This is an alternate means of controlling the magnetic field on the active surface 27 of cathode 24.

As shown in Figures 5, anode 34 is connected with an electrical conductor 71 to ground, a high voltage power supply 72, and low voltage power supply 73. The negative terminal of power supplies 72 and 73 are connected to an electrical conductor 74 leading to cathode carrier 41 and thereby connecting cathode 24 to the negative potential of power supplies 72 and 73. A rectifier 76 in line 74 prevents high voltage from power supply 72 to flow to power supply 73.

Housing 11 has a valve 78 to allow the introduction of an inert gas, such as Argon, as well as other gases and gas mixtures, into vacuum chamber 12. A second valve 77 can be a leakage valve used to adjust or

release the vacuum pressure in chamber 12.

In use, the cylindrical central magnet member 56 carried by the soft magnetic member 54 produces a circular symmetric closed fringing magnetic field. The geometry of anode 34 and cathode 24 is chosen so that the fringing magnetic field produced by the magnetic apparatus 53 is substantially normal to the electric field generated between cathode 24 and annular anode 34 when an appropriate electrical potential difference is applied to the anode and cathode. The magnetic apparatus 53 is used as an electron trap for electrons emitted from the active cathode surface 27 when a high voltage is applied to the cathode 24. A negative potential is applied to cathode 24. In the absence of a magnetic field in the vicinity of the cathode 24, a weak discharge is induced within the vacuum chamber. Inert gases, such as Argon and Krypton, are admitted into the chamber 12 via valve 78 to induce self-sustaining glow discharge. The discharge current is a function of gas species, chamber pressure, and applied voltage. When an electron trap is produced with an electric and magnetic field, a dense, ring-shaped plasma is produced close to the active surface 27 of the cathode 24.

The ring plasma generated by admitting Argon or other heavy inert gas into chamber 12 has sufficient conductivity to initiate a high current, low voltage arc discharge between the cathode 24 and anode 34. This is achieved by adjusting the vacuum pressure in the chamber to 0.1 to 500 X 10^{-3} mm HG or more through the admission of heavy inert gas, such as Argon, and applying a moderate negative potential of 100 to a few 1,000 volts DC from power supply 72 to the cathode 24 and anode 34. The simultaneous application of a high voltage, low current DC power supply 72 and a high current, low voltage DC power supply 76 to the cathode 24 and anode 34 generates a conductive plasma which in turn ignites the desired high current low voltage discharge. As soon as the arc is

ignited, the high voltage power supply 72 is disconnected. The arc produced is steered by the magnetic field of magnet apparatus 53 and coil 68 and sustains itself indefinitely. The arc track is determined by the shape of pole or member 56 and the annular ring configuration of member 54. In the embodiment of Figures 3 and 4, as illustrated in Figures 4 and 8, the arc track 60 is a circular band on active surface 27 of cathode 24. The inwardly directed vectors 70 represent magnetic fields parallel to the active surface 27.

Intense arc erosion occurring along the arc track 60 results in the formation of grooves on the active surface 27 of cathode 24. The erosion action is distributed more evenly over this surface by rotating the magnet apparatus 53 around axis 63. The rotation of the magnet apparatus 53 causes the arc track 60 defined by the magnet apparatus 53 to trace a cycloidal path on the active surface 27 of cathode 24. The dimensions of pole 56 and cathode 24 may be chosen so as to cause the arc path and hence arc erosion of the cathode to be confined to a ring-shaped region between circles 65 and 70 in Figure 4 of the active surface 27 of cathode 24. The inner radius 65 of this ring region can be made zero by the appropriate choice of magnetic axis 66 and the shape and dimensions of pole 56.

Circular arc track 60 in Figure 8 and rectangular arc track 79 in Figure 9, and connected circular arc track 81 in Figure 10 are realized with appropriate variations in the geometry of pole 56. Other closed arc tracks, such as triangular and elliptical, can be used. The condition to be met to fulfill generation of a closed arc track, such as track 60, 79, and 81, is the presence of a continuously turning magnetic field vectors 70 parallel to the active surface 27 of cathode 24, as shown in Figures 8, 9, and 10. It is only necessary that the field vectors be closed. Rectangle, triangle, ellipse, and other closed shapes for the arc track defined by

magnet apparatus 53 are sufficient to accomplish arc track control. Magnet apparatus 53 may be provided with suitable movements, such as translative movement, to more evenly distribute arc erosion on the cathode surface where non-circular arc tracks are used.

With strict arc track control, arc induced cathodic erosion is confined to the arc track. Using a time varying magnetic field of appropriate magnitude generated with coil 68, or coils 68 and 68A, the arc track can also be made to sweep over major portions of the active surface 27 of the cathode 24 to insure uniform cathode erosion. This insures high cathode material utilization efficiency when magnet apparatus 53 is not rotated.

As shown in Figure 5, object 32 is electrically connected to an independent power supply 40 operable to apply a positive or negative bias to the object. This bias is selected to optimize the adhesion or bond strength of the coating material covering the object. The power supply 40 can be a sputtering power supply used to clean the object. Object 32 can be connected to power supply 73 to serve as an anode for the primary or main arc.

Figure 6 is a diagram showing the ion motion in the vicinity of the arc column 81. The arc column 81 emanates from a spot indicated at 82 on the active surface 27 of the cathode. Vapors ejected from arc spot 82 are ionized as indicated at point 83. A portion of the ions 84 produced at 83 are ejected into the vacuum chamber 12. Other ions 85 move to the active surface 27 of the cathode and initiate a new arc spot at 87.

Figure 7 is a diagram showing the order of arc spot sequence along the closed arc path on the active surface of the cathode. The initial arc spot 82 is the start of the arc column 81 with ionization occurring at point 83. The arc spot sequence is illustrated by the reference numerals 87 to 95. The vectors X and & represent the plane of the active surface 27 of the cathode 24. The Z vectors represent the arc columns emanating from the

cathode spots 87-95.

Referring to Figures 11 and 12, there is shown a modification of the controlled vacuum arc material deposition apparatus of the invention indicated generally at 100. Apparatus 100 is operable to apply a plurality of materials to an object or part located in the vacuum chamber. The apparatus has a housing indicated generally at 101 surrounding a vacuum chamber 102. The housing 101 has a cylindrical sleeve-like side wall 103 attached to a top wall 104 and a bottom wall 106. An object 107, such as a turbine blade, is centrally located in chamber 102 and supported on an insulator 108. A source of vacuum 109 is coupled with hose 111 to housing 101 to evacuate the chamber 102. A valve 112 mounted on bottom wall 106 is used to introduce an inert gas, such as Argon, or other gases and gas mixtures, to vacuum chamber 102.

Three material deposition heads 113, 114 and 115 are mounted on circumferentially spaced portions of side wall 103. Side wall 103 is provided with suitable openings for each of the material deposition heads. The number of material deposition heads can vary. As shown in Figure 12, head 113 covers opening 116 accommodating anode 117. A solenoidal coil 118 surrounds head 113. An electric motor 119 drivably connected to a shaft 121 rotates the permanent magnet in the head 113.

The material deposition heads 113, 114 and 115 are identical in structure to head 18, as shown in Figures 3 and 5, and herein described. The description of the details of the head 18 and coil 68 are incorporated herein by reference. The cathodes of the heads 113, 114, and 115, can be of different materials so that the coating material that is deposited on the object 107 is a combination of the different materials of the cathodes. All of the material deposition heads 113, 114 and 115 can be simultaneously operated to produce the desired coating on object 107. Alternatively, one or more of the heads 113, 114, and 115, can be operated sequentially

to produce layers of coating materials on the object 107. The operation of the head 113 and coil 118 to control the arc path of the arc column is the same as herein described with reference to Figures 1 to 10. Metal vapors produced with the vacuum arc may be reacted with suitable gases or gas mixtures admitted through valve 112 to deposit single or multi-layered metal, ceramic and semi-conductor coatings.

While there has been shown and described two embodiments of the controlled vacuum arc material deposition apparatus and method, it is understood that changes in size, structure, arrangement of structure, electrical circuits, and materials of the anode and cathode, may be made by those skilled in the art without departing from the invention. The invention is defined in the following claims.

CLAIMS

1. An apparatus for applying material by vacuum arc deposition to an object comprising: housing means having a vacuum chamber accommodating the object, means for maintaining a vacuum in said chamber, at least one material deposition head attached to the housing means, a cathode mounted on said head, said cathode having an active surface in said vacuum chamber, anode means located in said vacuum chamber, means for generating and sustaining an electric arc between the active surface being vaporized by said electric arc and deposited on said object forming a coating thereon, magnet means located adjacent said cathode to establish a magnetic field generally parallel to the active surface of the cathode causing said electric arc to move in a continuously controlled arc track relative to the active surface of the cathode, and means movably mounting the magnet means on the head means operable to move the magnet means relative to the cathode whereby the arc track sweeps the active surface of the cathode.

2. The apparatus of Claim 1 wherein: said means movably mounting the magnet means includes means for rotating the magnet means about an axis generally normal to said active surface and offset from the magnetic axis of the magnet means whereby the arc track sweeps the active surface of the cathode.

3. The apparatus of Claim 2 wherein: said head has a cooling chamber, said cathode having a portion thereof located in the cooling chamber, said magnet means being located in said cooling chamber adjacent the portion of the cathode, and means for circulating cooling fluid through said cooling chamber.

4. The apparatus of Claim 3 including: rotatable shaft means mounted on the head supporting the magnet means in said cooling chamber.

5. The apparatus of Claim 2 including: coil means located around said head operable to modify the

magnetic field strength normal to said active surface of the cathode.

6. The apparatus of Claim 1 wherein: said head has a cooling chamber, said cathode having a portion thereof opposite the active surface located in the cooling chamber, said magnet means being located in said chamber adjacent the portion of the cathode, and means for circulating cooling fluid through said cooling chamber.

7. The apparatus of Claim 1 including: coil means mounted on the housing means operable to selectively reinforce or reduce the magnetic field strength normal to the active surface of the cathode.

8. The apparatus of Claim 1 including: electrical insulation means located between the housing means and head to insulate the head from the housing means.

9. The apparatus of Claim 1 wherein: said housing means has a wall having an opening in communication with the vacuum chamber, electrical insulation means mounted on the wall around the opening, said head being mounted on the insulation means to locate the cathode over said opening with the active surface thereof in the vacuum chamber, said anode means being aligned with said opening adjacent said active surface of the cathode.

10. The apparatus of Claim 9 including: sleeve means located in said opening to shield the insulation means to prevent cathode-anode shorting.

11. The apparatus of Claim 10 wherein: the anode means is a ring member having a portion surrounded by the sleeve means.

12. The apparatus of Claim 1 wherein: the magnet means comprises a permanent magnet having a recessed central pole and an annular means surrounding said pole.

13. The apparatus of Claim 1 wherein: said cathode is a member having a generally flat active surface, and

said anode means is an annular member located adjacent said active surface, said annular member having a sharp annular edge spaced from said active surface of the cathode.

14. The apparatus of Claim 1 wherein: a plurality of material deposition heads are attached to the housing, each head having a cathode with an active surface in the vacuum chamber, anode means located in the vacuum chamber, means for generating an electric arc between the active surface and said anode means, the material of said active surface of the cathodes being vaporized by said electric arc and deposited on said object forming a coating thereon, magnet means located adjacent said cathode to establish a magnetic field causing said electric arc to move in a continuously controlled arc track relative to the active surface of the cathode, and means movably mounting the magnet means on each head, means operable to move the magnet means relative to the cathode whereby the arc track sweeps the active surface of each cathode.

15. The apparatus of Claim 14 including: coil means located around each head operable to modify the magnetic field strength normal to said active surface of the cathode associated with each head.

16. The apparatus of Claim 14 wherein: each head has a cooling chamber, the cathode of each head having a portion thereof opposite the active surface located in the cooling chamber, said magnet means of each head being located in said chamber adjacent the portion of the cathode, and means for circulating cooling fluid through said cooling chamber.

17. The apparatus of Claim 14 wherein: each anode means is a ring member.

18. The apparatus of Claim 14 wherein: the magnet means of each head comprises a permanent magnet.

19. The apparatus of Claim 14 wherein: each anode means is an annular member, said annular member having

a sharp annular edge spaced from said active surface of the cathode.

20. The apparatus of Claim 1 including: first means providing a high voltage supply connected to the cathode and anode means, second means providing a low voltage supply connected to the cathode and anode means, and rectifier means connected to the first means and second means to allow ignition of the electric arc between the anode and cathode on application of high voltage from the first means and to sustain the electric arc with the low voltage from the second means upon termination of the high voltage.

21. The apparatus of Claim 1 wherein: the means for generating an electric arc includes power supply means providing a voltage, means for introducing a heavy inert gas into the vacuum chamber, said voltage, magnetic field and inert gas acting together to start the electric arc.

22. An apparatus for applying material by vacuum arc deposition to an object comprising: housing means having a vacuum chamber accommodating the object, means for maintaining a vacuum in said chamber, at least one material deposition head attached to the housing means, a cathode mounted on said head, said cathode having an active surface in said vacuum chamber, anode means located in said vacuum chamber, means for generating an electric arc between the active surface of the cathode and said anode means, the material of said active surface of the cathode being vaporized by said electric arc and deposited on said object forming a coating thereon, first means for establishing a magnetic field generally parallel to the active surface of the cathode causing the electric arc to travel along a closed arc track, and second means operable to control the magnetic field to cause the electric arc track to continuously sweep the active surface of the cathode.

23. The apparatus of Claim 22 wherein: the first means is a magnet means located adjacent the cathode for establishing said magnetic field, and said second means includes means to provide relative movement between the magnet means and cathode to control the sweep of the arc track.

24. The apparatus of Claim 23 wherein: the first means includes coil means located around the housing means operable to modify the magnetic field to control the arc track.

25. The apparatus of Claim 22 wherein: the first means includes coil means operable to establish a magnetic field to control the arc track.

26. The apparatus of Claim 25 wherein: the coil means includes a pair of coils located adjacent opposite sides of the anode means.

27. The apparatus of Claim 22 wherein: said head has a cooling chamber, said cathode having a portion thereof located in the cooling chamber, said first means being located in said cooling chamber adjacent the cathode, and means for circulating cooling fluid through said cooling chamber.

28. The apparatus of Claim 22 wherein: said housing means has a wall having an opening in communication with the vacuum chamber, electrical insulation means mounted on the wall around the opening, said head being mounted on the insulation means to locate the cathode over said opening with the active surface thereof in the vacuum chamber, said anode means being aligned with said opening adjacent said active surface of the cathode.

29. The apparatus of Claim 28 including: sleeve means located in said opening to shield the insulation means to prevent cathode-anode shorting.

30. The apparatus of Claim 1 wherein: a plurality of material deposition heads are attached to the housing, each head having a cathode with an active surface in the

vacuum chamber, anode means located in the vacuum chamber, means for generating an electric arc between the active surface and said anode means, the materials of said active surfaces of the cathode being vaporized by said electric arc and deposited on said object forming a coating thereon, first means to establish a magnetic field generally parallel to the active surface of the cathode causing an electric arc to travel along a closed arc track, and second means operable to control the magnetic field to cause the electric arc track to continuously sweep the active surface of each cathode.

31. The apparatus of Claim 30 including: coil means located around each head operable to modify the magnetic field strength normal to said active surface of the cathode associated with each head.

32. The apparatus of Claim 30 wherein: each head has a cooling chamber, the cathode of each head having a portion thereof opposite the active surface located in the cooling chamber, said magnet means of each head being located in said chamber adjacent the portion of the cathode, and means for circulating cooling fluid through said cooling chamber.

33. The apparatus of Claim 30 wherein: each anode means is a ring member.

34. The apparatus of Claim 30 wherein: the first means of each head comprises a permanent magnet.

35. The apparatus of Claim 30 wherein: each anode means is an annular member, said annular member having a sharp annular edge spaced from said active surface of the cathode.

36. The apparatus of Claim 22 wherein: the anode means is an annular member having a sharp annular edge spaced from the active surface of the cathode.

37. The apparatus of Claim 22 including: means for introducing a heavy inert gas into the vacuum chamber,

first power supply means providing a high voltage connected to the cathode and anode means, second power supply means providing a low voltage connected to the cathode and anode means, and rectifier means connected between the first and second power supply means to allow ignition of the electric arc between the anode means and cathode on application of high voltage from the first power supply means, said high voltage, magnetic field, and inert gas acting together to start arc ignition, said electric arc being sustained with the low voltage from the second power supply means upon termination of the high voltage.

38. The apparatus of Claim 22 wherein: the means for generating an electric arc includes power supply means providing a voltage, means for introducing a heavy inert gas into the vacuum chamber, said voltage, magnetic field and inert gas acting together to start the electric arc.

39. An apparatus for applying material by vacuum arc deposition to an object with a cathode having the active surface and an anode located in a vacuum chamber, and means for generating an electric arc between the active surface of the cathode and anode, the improvement of: first means located adjacent said cathode to establish a magnetic field causing the electric arc to travel along a closed arc track, and second means movably mounting the first means for movement relative to the cathode whereby the magnetic field of the first means causes the electric arc track to continuously sweep the active surface of the cathode.

40. The apparatus of Claim 39 wherein: the first means comprises magnet means including a permanent magnet.

41. The apparatus of Claim 39 wherein: said second means includes means for rotating the magnet means about an axis generally normal to the active surface of the cathode and offset from the magnetic axis of the magnet

means whereby the electric arc sweeps the active surface of the cathode.

42. The apparatus of Claim 39 including: means for cooling said cathode.

43. The apparatus of Claim 39 including: coil means located adjacent said first means operable to modify the magnetic field strength normal to said active surface of the cathode.

44. The apparatus of Claim 39 including: coil means surrounding said first means operable to selectively reinforce or reduce the magnetic field strength normal to the active surface of the cathode.

45. The apparatus of Claim 39 including: head means for supporting the cathode, said second means being movably mounted on the head means and supporting the first means adjacent said cathode.

46. The apparatus of Claim 45 including: coil means surrounding the head means operable to selectively reinforce or reduce the magnetic field strength normal to the active surface of the cathode.

47. The apparatus of Claim 45 including: housing means having said vacuum chamber, electrical insulating means supporting the head means on the housing means.

48. The apparatus of Claim 47 wherein: said housing means has a wall having an opening in communication with the vacuum chamber, said electrical insulation means being mounted on the wall around the opening, said head means being mounted on the insulation means to locate the cathode over said opening with the active surface thereof in the vacuum chamber, said anode being aligned with said opening adjacent said active surface of the cathode.

49. The apparatus of Claim 48 including: sleeve means located in said opening to shield the insulation means to prevent cathode-anode shorting.

50. The apparatus of Claim 49 wherein: the anode is a ring member having a portion surrounded by the sleeve means.

51. The apparatus of Claim 39 including: means for introducing a heavy inert gas into the vacuum chamber, first power supply means providing a high voltage connected to the cathode and anode means, second power supply means providing a low voltage connected to the cathode and anode means, and rectifier means connected to the first and second power supply means to allow ignition of the electric arc between the anode means and cathode on application of high voltage from the first power supply means, said high voltage, magnetic field, and inert gas acting together to start arc ignition, said electric arc being sustained with the low voltage from the second power supply means upon termination of the high voltage.

52. A method of vacuum arc deposition of material on an object with an active surface of a cathode and an anode comprising: establishing a vacuum in a chamber accommodating an anode and an active surface of a cathode, applying opposite electrical potential to said anode and cathode to establish and maintain an electric arc between said anode and cathode, providing a controlled electric arc track, and sweeping the active surface of the cathode with the controlled electric arc track by moving a magnetic field relative to the cathode.

53. The method of Claim 52 wherein: the sweep path of the electric arc track is controlled moving a magnet means relative to the cathode along a selected closed path.

54. The method of Claim 52 including: modifying the magnet field with a solenoid generated magnetic field to control the electric arc track.

55. The method of Claim 52 including: superpositioning a solenoid generated magnetic field on the magnetic field to reduce the normal component of the magnetic field.

56. The method of Claim 52 including: cooling the cathode to dissipate the heat of the cathode generated by the electric arc.

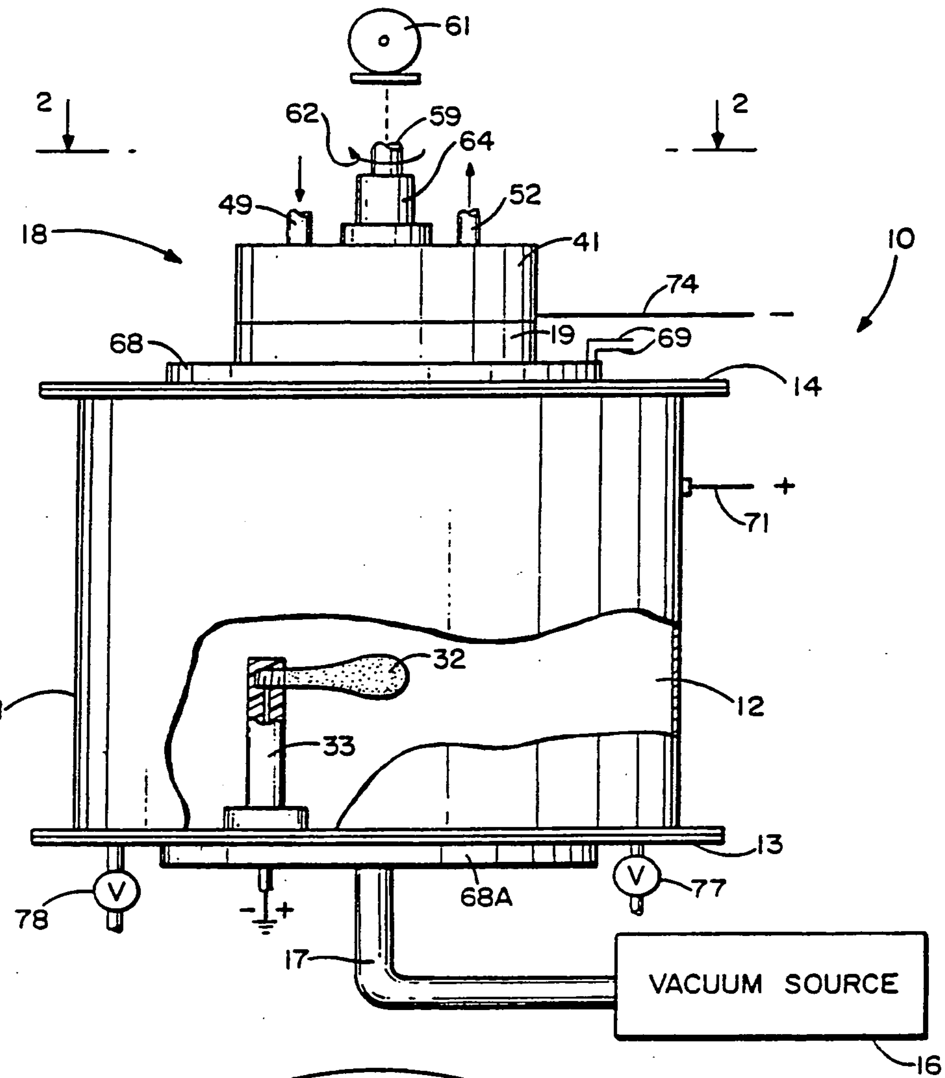
57. The method of Claim 52 wherein: the sweeping of the active surface of the cathode with the electric arc track is achieved by rotating magnet means relative to the cathode about an axis extended generally normal to said active surface of the cathode.

58. The method of Claim 52 wherein: the track of the electric arc is controlled by controlling a magnet field with a solenoid coil.

59. The method of Claim 52 wherein: the electric arc is established by introducing an inert gas into the vacuum chamber, applying a high voltage to establish an electric arc, said inert gas, high voltage, and magnetic field acting together to start the electric arc, applying a low voltage to maintain the electric arc, and terminating the high voltage.

60. The method of Claim 52 wherein: the electric arc is established by supplying a heavy inert gas to the vacuum chamber, maintaining the vacuum chamber at a selected vacuum pressure, and applying a first high voltage power supply to establish an electric arc, said first high voltage, inert gas, and magnetic field acting together to start the electric arc.

61. The method of Claim 60 wherein: the electric arc is maintained with a second low voltage power supply upon termination of the first power supply.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VACUUM SOURCE
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FIG. 1

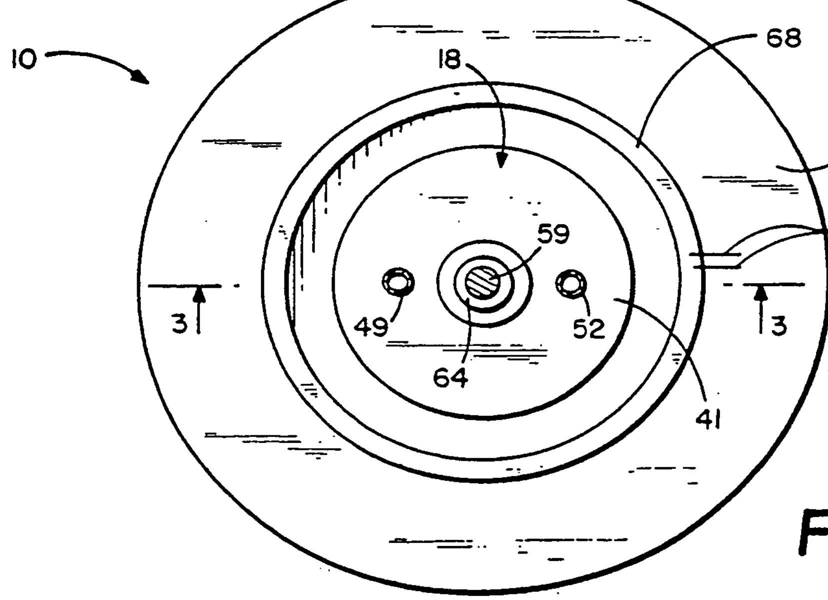
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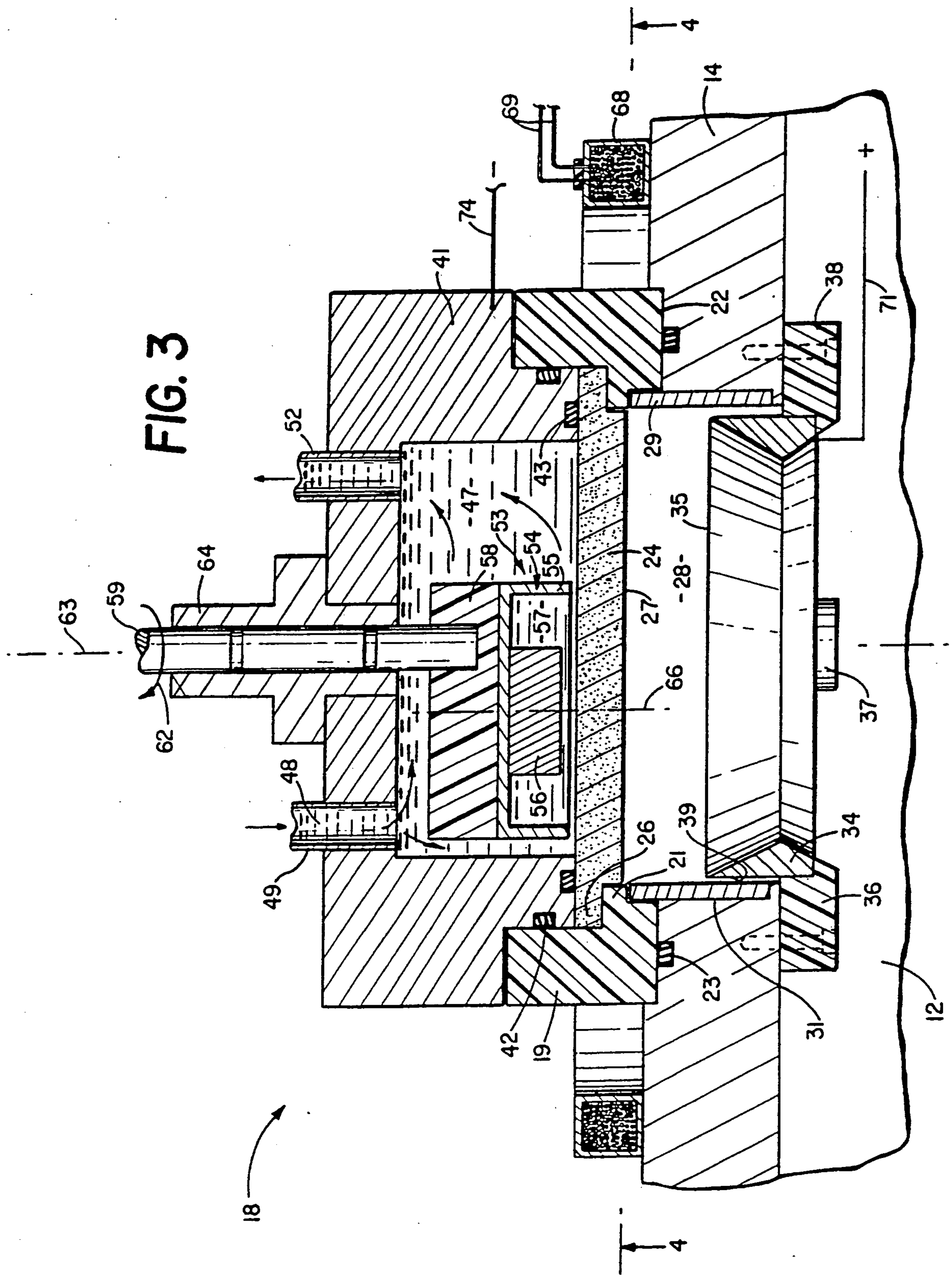
FIG. 2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18

FIG. 3

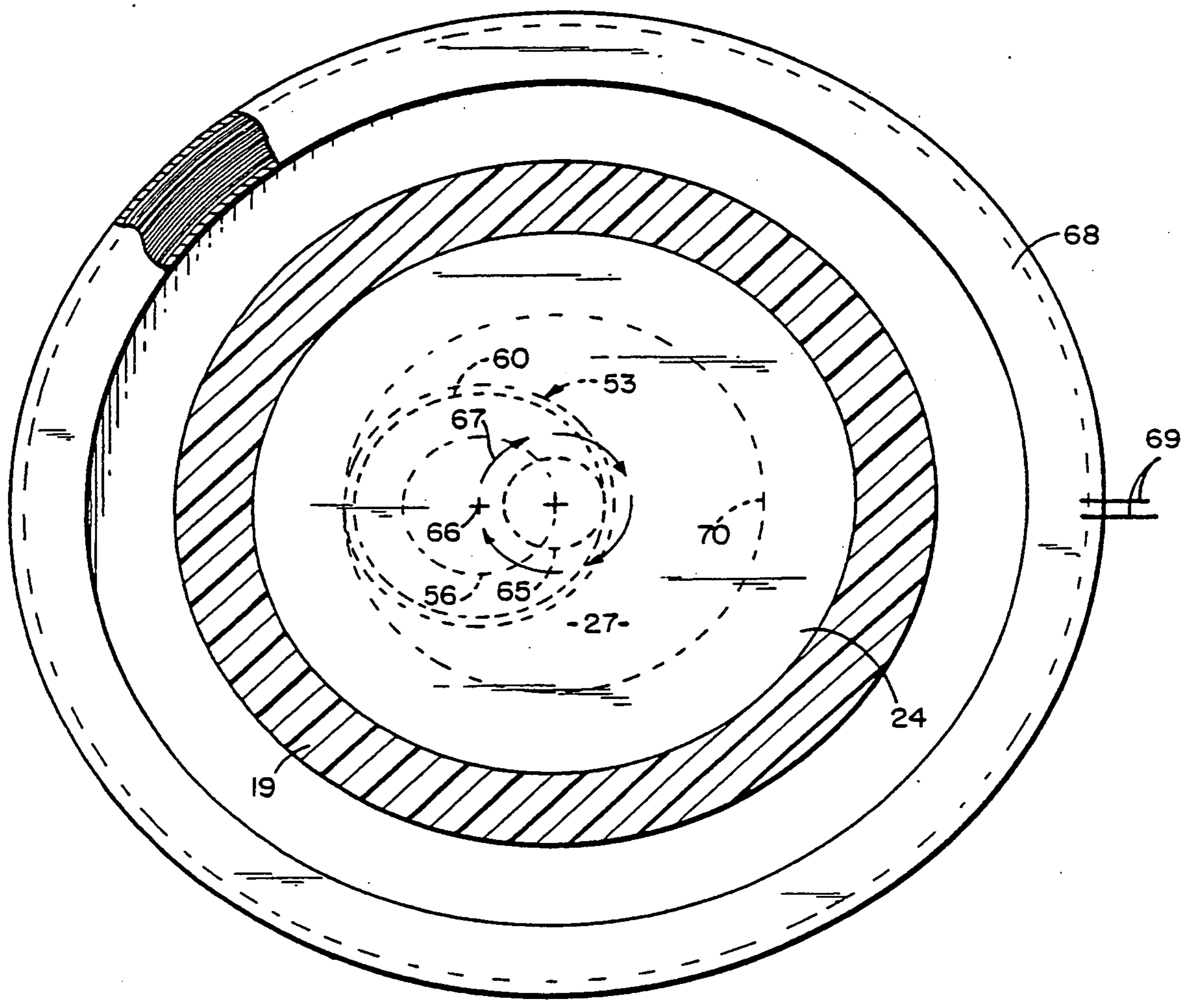


FIG. 4

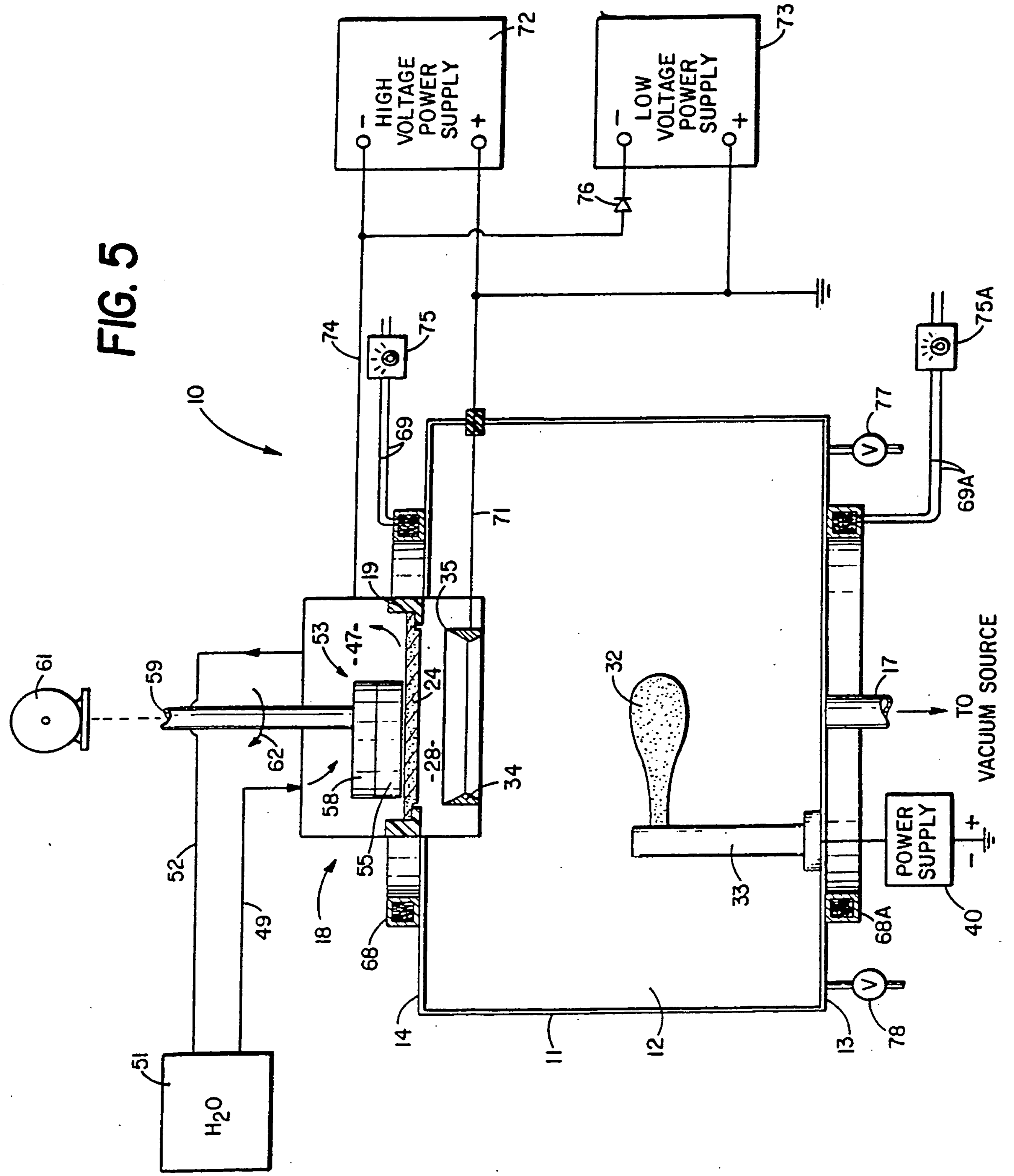
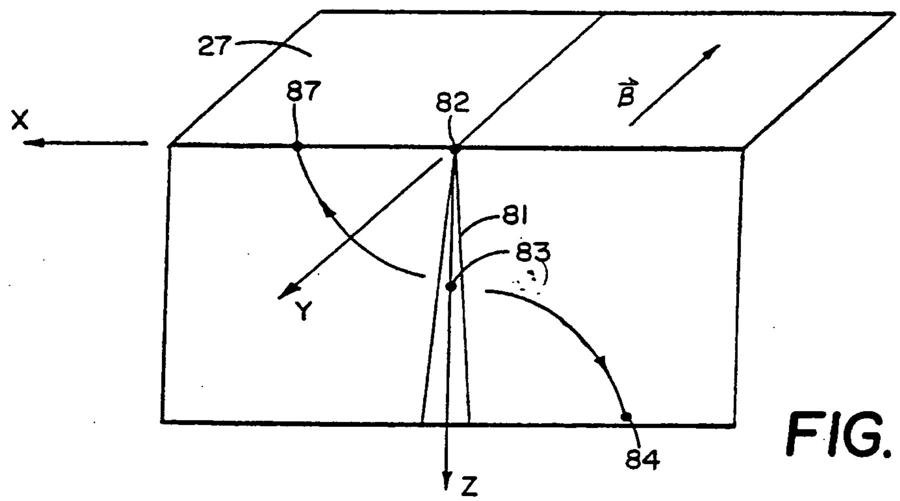

HIGH VOLTAGE POWER SUPPLY
LOW VOLTAGE POWER SUPPLY
POWER SUPPLY
TO VACUUM SOURCE
H_2O

FIG. 5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87
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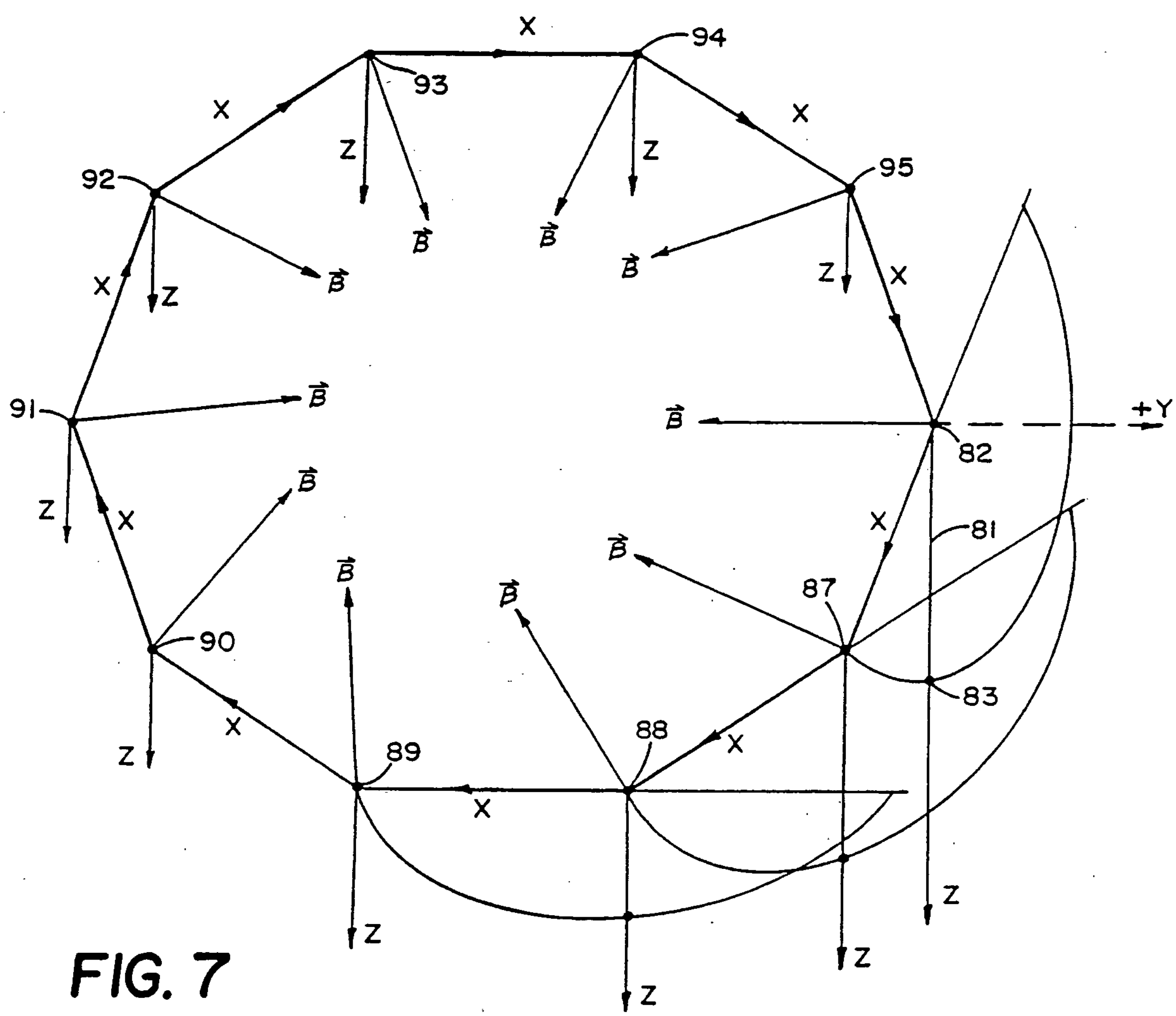
X
B
81
83
Y
84
Z

FIG. 6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95
B
B
B
B
X
Z
Z
X
B
B
+Y
91
82
Z
X
B
X
81
B
B
B
87
90
83
88
X
X
89
X
Z
Z
Z
Z
Z

FIG. 7

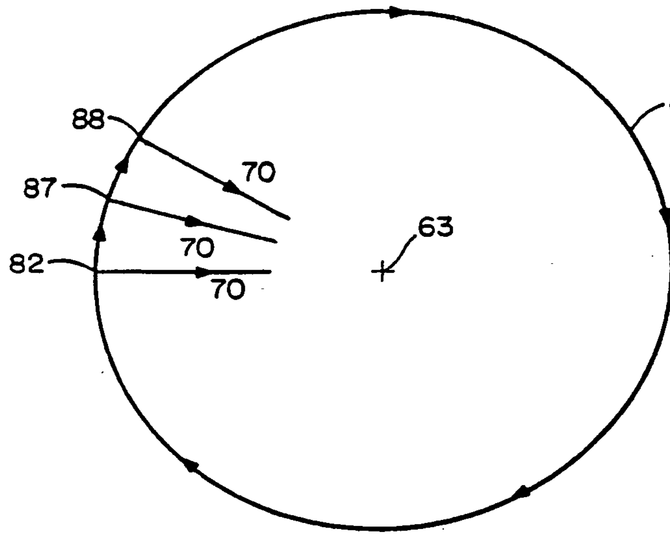

FIG. 8

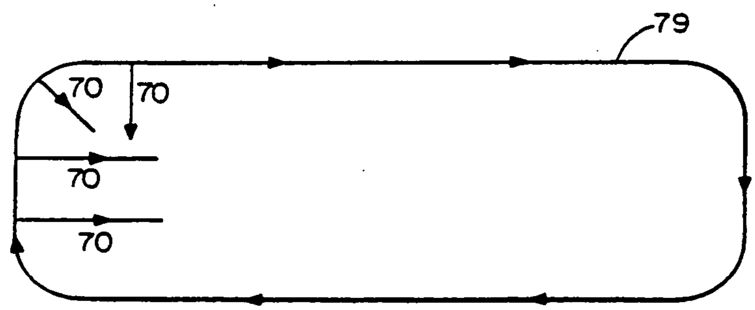

FIG. 9

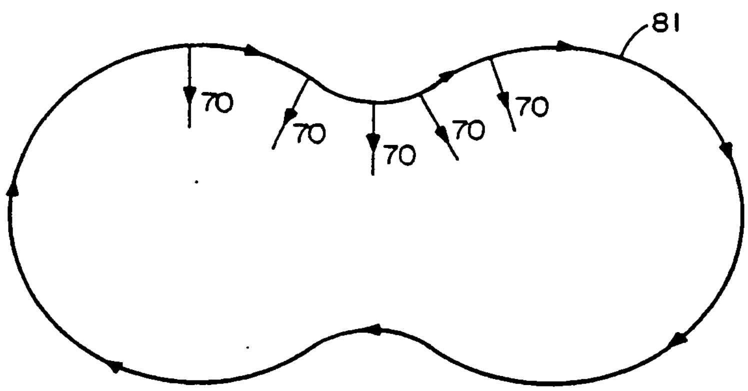

FIG. 10

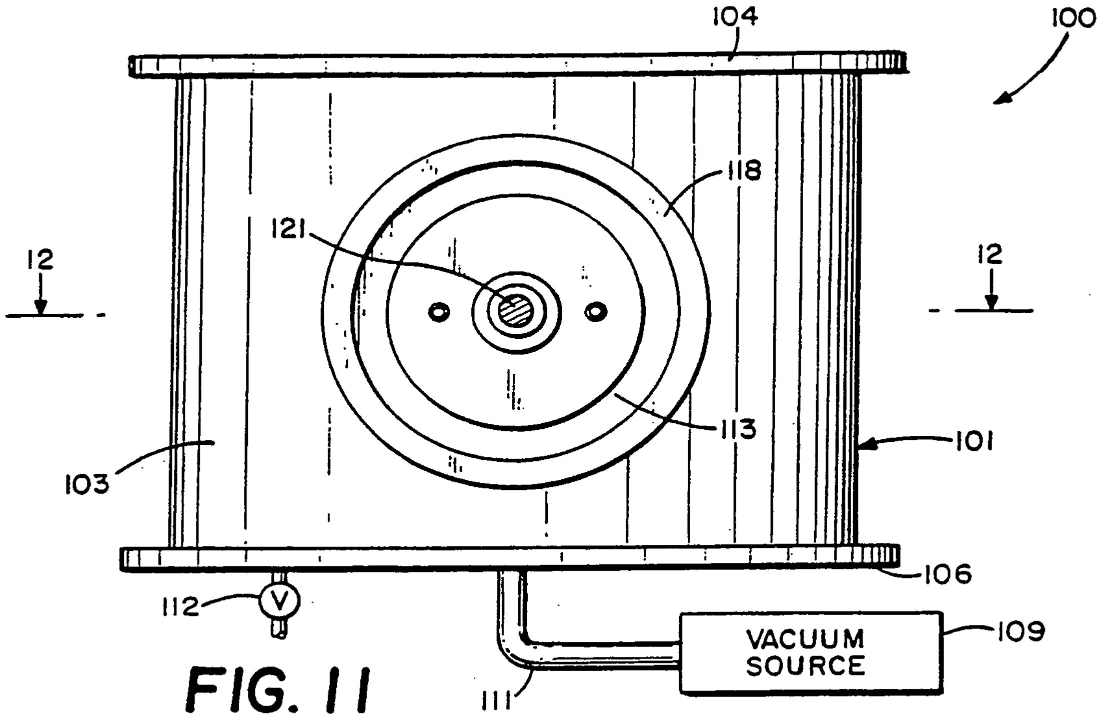
104
100
118
121
12
12
113
101
103
106
112
V
VACUUM SOURCE
109
111

FIG. 11

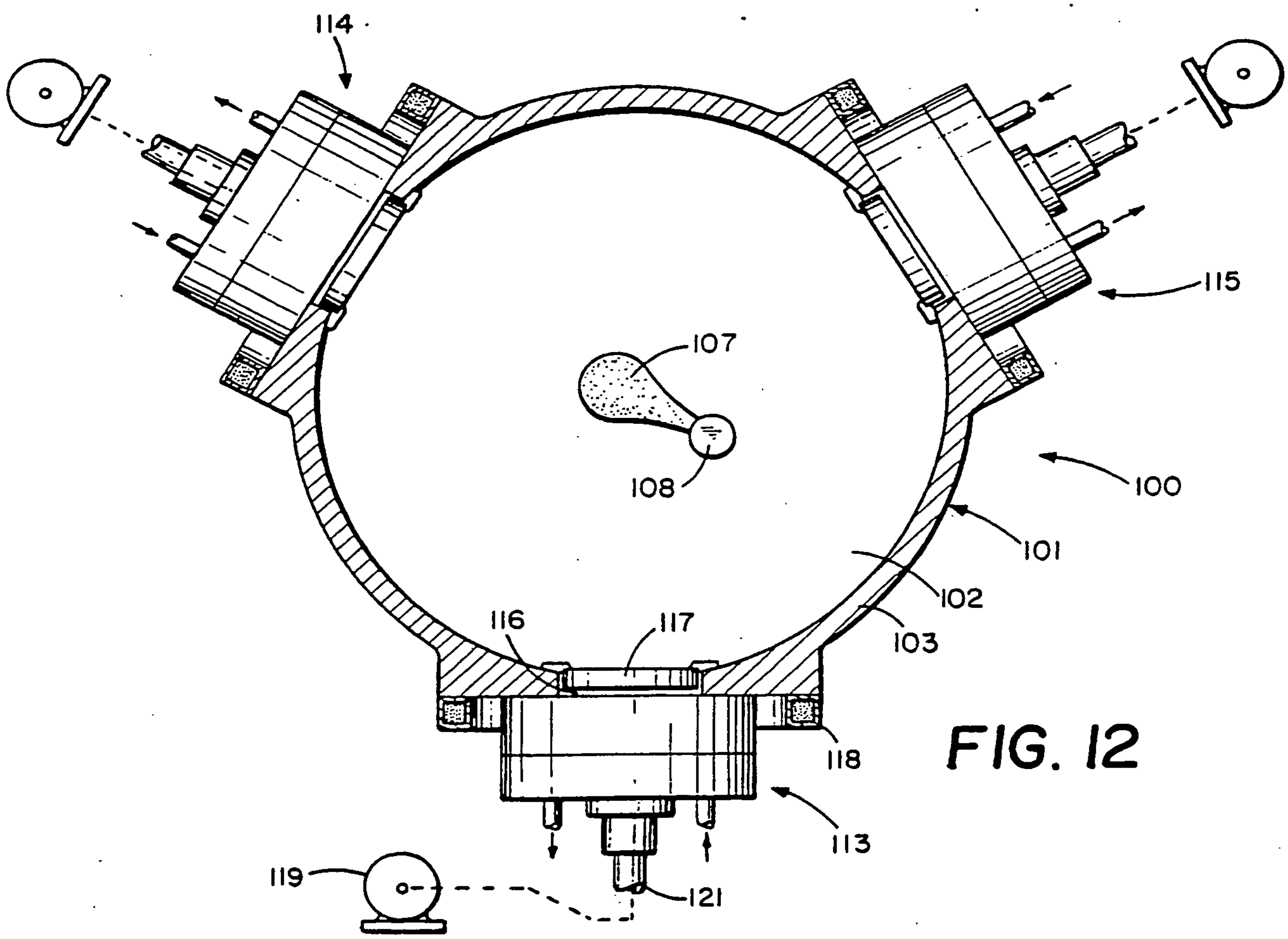
114
115
107
108
100
101
102
103
116
117
118
113
119
121

FIG. 12

INTERNATIONAL SEARCH REPORT

International Application No PCT/US85/00312

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.[4] C23C13/12 C23C 15/00
U.S. Cl. 204/298, 118/50.1, 723, 219/121P, 313/160

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	204/164, 192R, 298 118/50.1, 723 427/37, 47 219/76.16, 121P, 121 PL, 121 PV 313/160, 161 315/338, 344

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US, A, 3,625,848, 07 December 1971 Snaper	1-61
A	US, A, 3,783,231, 01 January 1974 Sablev et al	1-61
Y	US, A, 3,956,093, 11 May 1976 McLeod	5, 7, 15, 24-26, 31, 43, 44, 46, 54, 55, 58
P	US, A, 4,444,643, 24 April 1984 Garrett	2-5, 7-12, 15, 24-26, 28, 29, 31, 41, 43, 44, 46-50, 54-55, 57, 58
P	US, A, 4,448,659, 15 May 1984 Morrison, Jr.	1-61

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
03 May 1985	10 MAY 1985
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	William Leader William Leader

Form PCT/ISA/210 (second sheet) (October 1981)

International Application No. PCT/US85/00312

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No [18]
P	US, A, 4,448,799, 15 May 1984 Bergman et al	2-5, 7-12, 15, 24-26, 28, 29, 31, 41, 43, 44, 46-50, 54, 55, 57, 58
A	SU, A, 307,666, 05 January 1979	1-61
Y	SU, A, 363,375, 05 January 1979	1-61